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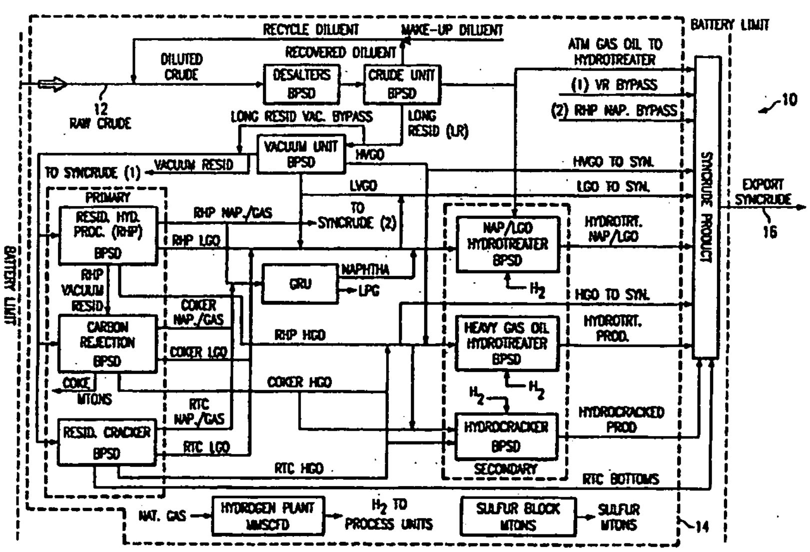

(57) Abstract: A computerized system for facilitating design of a manufacturing process system having a plurality of process units includes a linear program model, a processor, and a memory accessible by the processor. The linear program model forms a plurality of linear equations describing constraints on the manufacturing process system. The linear equations include as variables price information associated with at least one input product and at least one output product of at least one of the process units. The computerized system also includes a linear program engine stored on the memory and operable to be executed on the processor. The linear program engine is further operable to generate an optimal solution for the system of linear equations.

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METHOD AND SYSTEM FOR PROCESS DESIGN

TECHNICAL FIELD OF THE INVENTION

This invention relates generally to industrial processes and more particularly to a method and system for process design.

BACKGROUND OF THE INVENTION

Refineries, petrochemical plants, and chemical plants all produce products necessary to modern society. Such products include consumer goods, for example, gasoline and motor oil, as well as industrial goods, for example, industrial chemicals.

These goods are produced by an industrial process. In an industrial process, raw materials are supplied as inputs to the process and the desired goods are produced as an output of the process. In addition, intermediate outputs may be generated as a by-product to the process. Creating the output products from the raw material(s) often requires a number of processing steps, and the processing steps generally require various machines for implementing these steps. The process many times requires many steps and numerous associated machines depending upon the desired output products.

As the number of processing steps required increases, the complexity in designing an economical process increases dramatically. For example, a number of alternative series of steps may be used to produce the same result, and a determination of which series of steps is most economical is desirable. Computer models are conventionally used to facilitate this optimization process. In the process industry, linear program-based models are widely used to optimize the operation of existing plants. Several application software programs are currently available in the market to develop plant models for this purpose. Examples of these application software programs include Process Industry Modeling System (PIMS) marketed by Aspen Technology, Inc., Refinery Planning and Modeling System (RPMS) by Bonner & Moore, and Generalized Refinery

Transportation Marketing Planning System (GRTMPS) by Haverly Systems, Inc. Linear program-based models refer to models of a system that consists of a linear set of equations that are solved for an optimal solution. In addition to utilizing linear program models for optimizing the operation of existing plants, linear program models are also used for planning purposes, including potential modifications to an existing plant or building a new facility.

Although linear program-based models are used to some extent, conventional design techniques using available linear program-based models are more time-consuming than desired and do not necessarily provide sufficient information to allow a designer to readily assess the relative desirability of a plurality of design options.

SUMMARY OF THE INVENTION

Accordingly, a need has arisen for an improved method and system for process design. The present invention provides an apparatus and method for determining the design for a process that addresses shortcomings of prior systems and methods.

According to one embodiment of the invention, a computerized system for facilitating design of a manufacturing process system having a plurality of process units includes a linear program model, a processor, and a memory accessible by the processor. The linear program model forms a plurality of linear equations describing constraints on the manufacturing process system. The linear equations include as variables price information associated with at least one input product and at least one output product of at least one of the process units. The computerized system also includes a linear program engine stored on the memory and operable to be executed on the processor. The linear program engine is further operable to generate an optimal solution for the system of linear equations.

According to another embodiment of the invention, a computerized method for designing a manufacturing process having a plurality of units includes providing to a linear program engine data representing a plurality of linear equations describing constraints on the manufacturing process, the linear equations including, as a variable, energy flow information associated with at least one of the plurality of units. The method also includes optimizing based on a predetermined criteria the linear equations using the linear program engine. In response to the

optimization, a description of the manufacturing process is generated.

According to yet another embodiment of the invention, a computerized system for facilitating design of a manufacturing process system having a plurality of process units includes a processor, a memory accessible by the processor, and a linear program model. The linear program model forms a plurality of linear equations describing constraints on the manufacturing process system. The linear equations include discrete capital cost information for at least one of the plurality of process units. The discrete capital cost information includes data representing quantified capital costs associated with redundant process units. The system also includes a linear program engine stored in the memory and operable to be executed on the processor and further operable to generate an optimal solution for a system of linear equations.

Embodiments of the invention provide numerous technical advantages. For example, in one embodiment of the invention, a system is provided that allows rapid evaluations of a number of alternative process configurations. Because of this rapid evaluation, additional alternative scenarios can be considered. Further evaluations are performed with significant savings in man-hours and project costs. According to the same embodiment, competing technologies for various process steps may be evaluated and compared.

Although the teachings of the invention may be used in the design of a variety of systems, applications to which the invention is particularly pertinent include determining efficient routes to interlink intermediate streams produced within refinery process units and to processes that convert

a gas stream to liquid products. The invention may also be used in determining efficient routes for utilization of utilities and energy streams such as in gas to liquid conversion processes.

Other technical advantages are readily apparent to one skilled in the art from the following figures, descriptions, and claims.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of the present invention and the advantages thereof, reference is now made to the following descriptions taken in connection with the accompanying drawings in which:

FIGURE 1A is a block diagram of an example industrial process;

FIGURE 1B is a conceptual block diagram of the process of FIGURE 1A;

FIGURE 2A is a block diagram showing steps of a process for converting a feed into intermediate and final products;

FIGURE 2B is a block diagram showing a particular selection of steps to be performed in converting a feed to intermediate and final products;

FIGURE 2C is an alternative process to that of FIGURE 2B for converting feed to intermediate and final products;

FIGURE 3 is a block diagram illustrating a computer system for automatically generating and evaluating an industrial process and for providing a preferred solution for the process according to the teachings of the invention;

FIGURE 4 is a block diagram of a portion of the system of FIGURE 3 illustrating additional details of particular modeling techniques according to the teachings of the inventory;

FIGURE 5 is a block diagram of a spreadsheet for use as an interface in the computer system of FIGURE 3;

FIGURE 6 is a flow chart illustrating a method for utilizing the system of FIGURE 3 to obtain a design for a plant process;

FIGURE 7 is a graph illustrating that the heat in a reactor effluent stream may be split into many energy streams;

FIGURE 8 is a flow chart illustrating an example reactor model;

FIGURES 9A through 9C are block diagrams illustrating energy sinks;

FIGURES 10A through 10C are block diagrams illustrating an example energy utilization scenario;

FIGURE 11 is a block diagram illustrating a utility balance incorporated into the system of FIGURE 3;

FIGURE 12 is a block diagram illustrating example utility producers and utility users for an example manufacturing process;

FIGURE 13 shows cost curves generated according to both conventional methods and according to the process of FIGURE 14;

FIGURE 14 is a flow chart illustrating the generation of the cost database illustrated in FIGURE 3; and

FIGURES 15A through 15C are alternative processing steps for the system shown in FIGURE 1A that were generated and compared by the system of FIGURE 3.

DETAILED DESCRIPTION OF THE INVENTION

Embodiments of the present invention and its advantages are best understood by referring to FIGURES 1 through 15C of the drawings, like numerals being used for like and corresponding parts of the various drawings.

FIGURE 1A is a block diagram illustrating an example industrial process 10 designed according to the teachings of the present invention. Process 10 receives inputs 12 and produces outputs 16. In this example input 12 is raw crude and output 16 is syncrude. In order to generate syncrude 16 from raw crude 12, a plurality of processing steps 14 are performed. Although FIGURE 1A illustrates one particular set of processing steps 14, other processing steps could be used to generate syncrude 16 from raw crude 12. As illustrated, the number of processing steps 14 may be numerous, resulting in great complexity in comparing the desirability of one set of processing steps 14 to an alternative set of processing steps 14.

According to the teachings of the present invention, a computer system is provided that automatically evaluates a number of relevant variables and generates a desirable set of processing steps 14 based on a given criteria. In the examples described herein, the desired criteria is internal rate of return. Internal rate of return refers to the economic rate of return on the investment and operating costs of a given process 10 as realized from the generation of outputs 16. For simplicity of description, a simplified block diagram of FIGURE 1A is illustrated in FIGURE 1B.

As shown in FIGURE 1B, process 10 receives crude feeds 12 as inputs and generates syncrude 16 as an output. A plurality of units associated with processing steps 14 are illustrated. A front end distillation unit 18 receives

crude feed 12. Front end distillation unit 18 provides intermediate product 40 to primary upgrading units 22 and intermediate product 30 to syncrude and distillates pool 50. Pool 50 collects syncrude and distillates. Front-end distillation unit 18 also generates a diluent recycle as denoted by reference numeral 28.

Primary upgrading units 22 perform various functions related to processing intermediate product 40, advancing the final product toward syncrude. Primary upgrading units 22 cooperate with auxiliary units 20 as denoted by reference numerals 32 and 34 to generate intermediate products 36 and 38. In addition, auxiliary units 20 cooperate with secondary upgrading units 24 as denoted by arrows 42 and 44 to generate intermediate products and distillates 46. Primary upgrading units produce intermediate products and distillates 38 that are provided to syncrude and distillates pool 50. Included within steps 14 is utilities and offsites unit 26, representing utilities associated with the described processing units and additional units that do not directly receive feed or intermediate products. Process 10 results in syncrude 16 from syncrude/distillates pool 50.

A number of alternative processing steps may be represented by process 10 illustrated in FIGURE 1B. The present invention allows selection of an optimal process 10. The selection of a particular process is described in conjunction with FIGURE 15A below and its desirability over other alternative processes is described in conjunction with FIGURES 15B and 15C.

FIGURE 2A is an illustration of a complex processing scheme 56 that requires many processing steps to convert a feed 52 to intermediate and/or final products 54. Each

block 58, 60, 62, 64, 66, 68, 70, 72, 74, 76 represent individual processing steps. The method of the present invention determines a preferred integrated route interconnecting individual processing steps including interactions between the processes and different technologies that maximizes a desired criteria. In the described examples, that criteria is the internal rate of return and/or the best configuration for a certain set of economic parameters.

FIGURE 2B and 2C show examples of two possible ways, 78 and 119, to interconnect processing steps. In FIGURE 2B a processing step 80, a processing step 82, and a processing step 86 are performed, resulting in intermediate and final products 54. By contrast, the process in FIGURE 2C utilizes steps 80, 84, and 86 resulting in intermediate and final products 54. In addition to incorporating alternative steps, alternative flows of intermediate products such as intermediate products 88, 90, 92, 94, 101, 110, 112, 116, 114, and 118 are utilized.

Actual complex process plants generally incorporate greater complexity in numerous possible processing steps and competing combinations of processing routes, making the route selection process very complex and time consuming. The present invention addresses this problem.

FIGURE 3 illustrates a system 120 for modeling and optimizing processes such as those described in FIGURES 1A through 2C. According to the present invention, system 120 generates a preferred solution quicker than conventional methods and additionally considers factors that result in more accurate determinations of the economically optimal solution.

System 120 includes a linear program engine 122 and an interface 124. Stored for use with the linear program engine 122 is a linear program model 125 and a project results output 130. Interface 124 allows both automatic and manual communication with linear program model 125. Linear program model 125 forms a set of linear equations as inputs to linear program engine 122 that define a process to be optimized. Linear program engine 122 is operable to solve those equations for a preferred solution, or "program." Suitable examples of linear program application software include Process Industry Modeling System (PIMS) marketed by Aspen Technology, Inc., Refinery Planning in Modeling System (RPMS) by Bonner & Moore, and Generalized Refinery Transportation Marketing Planning System (GRTMPS) by Haverly Systems, Inc.; however, other suitable systems may be used. All of these application software include a linear program engine 122 such as CPLEX and a language to construct the LP model. Linear program engine 122 is implemented through use of such an application software executed on a processor having an associated memory for storing the software application as well as other information.

Linear program engine 122 receives inputs from linear program model 125 and provides outputs through user interface 124. Inputs may include feed and product description and prices 128, constraints 134, process submodels 132, capital investment cost curves 135, and unique modeling techniques 136. In one embodiment, these inputs are provided in the form of a plurality of spreadsheets. Linear programming engine 122 may also generate project results report 130 providing a determination of a preferred solution based upon the

provided inputs. Information is placed into linear program model 125 in a format suitable for execution by linear program engine 122 by interface 124 and in particular, by use of spreadsheets 410 and smart links 126, described below.

FIGURE 4 is a block diagram of unique modeling techniques 136. Unique modeling techniques include intermediate product pricing 510, energy integration 520, utility balances and integration 530, linear and nonlinear mathematical models to calculate yields and properties 540, estimation of capital costs and operating costs inclusive of inflation 550, and calculation of major economic parameters for project evaluation 560. Each of these modeling techniques is described in greater detail below.

With reference to FIGURE 3, interface 124 receives input information for generating linear program model 125 from a number of sources. These sources include spreadsheets 410, inputs 138, smart spreadsheets 142, a cost database 144, an operating data/licensor information database 146, an external process simulation results 148, a utility database 150, and process models 152. Receipt of input information by interface 124 is described in greater detail below in conjunction with FIGURE 5. Interface 124 also receives project results report 130 generated by linear program engine 122 and provides the report to the user as output 140, as described in greater detail in conjunction with FIGURE 5.

Interface 124 also includes a plurality of smart links 126. Smart links 126 provide an efficient way for linear program engine 122 to receive information as inputs on Smartlinks 126 are macros that update information within

linear program model 125 with information provided by a user in spreadsheets 410.

According to one embodiment, interface 124 incorporates Excel spreadsheets 410, illustrated best in FIGURE 5, for allowing a user to easily modify linear program model 125. Spreadsheets 410 includes locations for storing three types of information: input information 412, output information 414, and help information 416.

The following input windows are provided: a problem description 418, a crude selection 420, process units 422, tank storage 424, product specifications 426, product requirements 428, feed and product pricing 430, and economic parameters 432. Details of each of these categories of information and the input of such information into spreadsheets 410 is described in greater detail below.

Problem description window 418 is a summary description of the problem to be solved. The summary description is generated or modified by a user of system 120, except for some descriptions which are automatically changed.

Crude selection window 420 is used to select the feed that is converted by the process to be designed into a final end product. All crudes currently available are presented to the user. The user may modify the minimum and maximum throughput constraints for the crude or mix of crudes fed to the refinery and may specify an Overall Onstream Factor for an entire refinery. Overall Onstream Factor refers to number of operating days in a year (less than or equal to 365).

Based on the constraints, the feed is calculated by spreadsheets 410. Crude selection window 420 also allows specification by the user of crude price and diluent

selection. Diluents are primarily utilized with extra heavy crudes to facilitate transportation and handling. After the desired information is provided within crude selection window 420, an "UPDATE" function allows smart links 126 to modify linear program model 125 with the provided information for optimization by linear program engine 122.

Process units window 422 allows entry of information for process units in three categories: (1) distillation/primary upgrading units, (2) secondary upgrading/finishing units, and (3) auxiliary units. These categories of process units correspond to primary upgrading units 22, secondary upgrading units 24, and auxiliary units 20, respectively, illustrated in FIGURE 1B. Each category of process units is associated with an input table that allows the user to specify minimum and maximum throughput constraints for each unit. The user also typically specifies if there is any existing capacity available for these units. Individual unit onstream and design factors may also be entered. An "UPDATE" function allows smart links 126 to modify linear program model 125 with the provided information for optimization by linear program engine 122.

Tank storage window 424 allows a user to specify either the number of days of storage or the total storage capacity for each of three types of storage: feed, product, and intermediate storage. Additionally, the type of tanks and any existing storage capacity available can be specified. An "UPDATE" function allows smart links 126 to modify linear program model 125 with the provided information for optimization by linear program engine 122.

Product specification window 426 allows the user to specify product specifications. For example, product specifications for a typical refinery are divided into a number of major categories: LPG, gasoline, kerosene, diesel, fuel oil, and syncrude. An "UPDATE" function allows smart links 126 to modify in linear program model 125 with the provided information for transmission to linear program engine 122.

Product requirements window 428 allows the user to specify the minimum and maximum production required. An "UPDATE" function allows smart links 126 to modify linear program model 125 with the specified information for transmission to linear program engine 122.

Feed and product pricing window 430 allows the user to make changes to the feed, product, and utilities prices. For example, the price of crude is specified in a "CRUDE SELECTION" sheet. An "UPDATE" function allows smart links 126 to modify linear program model 125 with the specified information for optimization by linear program engine 122.

Economic parameters window 432 allows the user to define overall economic parameters that govern the given process configuration of a given process complex. These parameters include the number of years required for capital recovery and the number of operating days in the year. The user may specify the number of years, and the number of operating days in the year is determined by spreadsheets 410 based on the Overall Onstream Factor defined in crude selection window 420. The user may also select a geographical cost basis for the project and construction year, impose a maximum allowable Total Investment Cost. The economic parameters also provides for apportionment of labor cost, dependent on site and craft labor availability,

in construction of such facilities. Additional factors may also be included in this window, including inflation factors, type of depreciation and tax rate. An "UPDATE" function allows smart links 126 to modify linear program model 125 with the specified information for transmission to linear program engine 122.

When displaying output information received from interface 124 using an "UPDATE RESULTS" function 434, the process utilizes the following output windows illustrated in FIGURE 5: block flow diagram 436, capacity utilization/Total Investment Cost (TIC) 438, finished products 440, utility summary 442, and economic analysis 444. Some of these windows display information in tabular form.

"UPDATE RESULTS" function 434 automatically updates all result tables.

Block flow diagram window 436 displays a block flow diagram of the designed processing complex. The distribution of all streams going through the distillation units, primary upgrading units, secondary upgrading units, and finishing units is illustrated. Auxiliary units are also displayed. A second block flow diagram showing gas plants and some additional finishing units may be accessed from this window. Inter unit transfer flows and unit capacities are displayed.

Capacity utilization/total investment cost window 438 provides information related to capacity utilization and Total Investment Cost of each unit and system and is organized into five or more components. Typically, for a refinery complex they are: Total Investment Cost Summary, Distillation/Primary Upgrading Units, Secondary Upgrading/Finishing Units, Auxiliary Units, and Offsites

and Misc. Total Investment Cost Summary provides the user an overall view of the Total Investment Cost for each block of process unit types. The other components provide more detailed information for each individual unit.

Finished products window 440 is divided into product categories from the complex. For example: Product Summary, Gasoline grades, Kerosene/Jet Fuel, Diesel grades/Fuel Oil grades, and Syncrude. Product Summary is a summary of the production constraints and total production. The other categories include detailed information on the composition of each blend.

Utility/Summary 442 includes four summary tables: Overall Utility Balance, Distillation/Primary Upgrading Units, Secondary Upgrading/Finishing Units, and Auxiliary Units. The Overall Utility Balance table summarizes total utilities consumed by the designed refinery. The other tables show the utilities consumed by each unit of the designed refinery.

Economic analysis window 444 contains estimated Total Investment Cost for the designed processing complex, the operating costs and revenue, and the project's internal rate of return. This information is automatically retrieved from results/output report 130 generated by linear program engine 122.

Help location 416 stores help information related to system 120.

In generating linear program model 125, interface 124 also communicates with a number of databases, including cost database 144, operating detail licensor information database 146, process simulation database 148, utility database 150, and process models database 152 in addition to communicating with smart spreadsheets 142.

Interface 124 also communicates with a cost database 144. Cost database 144 includes information related to the cost of units and systems and is described in greater detail below in conjunction with FIGURES 13 and 14.

Interface 124 also communicates with an operating data and licensor information database 146. This communication allows estimation of operating cost of each unit/system. The database can be updated with information from technology licensors.

Interface 124 also communicates with utility database 150. Utility database 150 allows estimation of utility requirement for each unit and/or system.

Interface 124 also communicates with process model database 152.

FIGURE 6 is a flow chart illustrating a method for utilizing system 120 of FIGURE 3 to obtain a design for a plant process. The method begins at step 162. Initially, the nature of the project and project objectives are defined. At a step 164 a determination is made of whether the design is a grassroots design, which refers to an initial design as opposed to a redesign of an existing system, or whether the design involves revamp of an existing facility. If a grassroots design is required, a determination is made at step 166 of whether customization is required. A basic default model for linear program model 125 includes a number of processing steps as well as yield data, product properties, utilities requirement, and capital and operating costs for each processing step. Customization refers to defining new process units or utilizing more accurate yield or operating data that may be available. If customization is not required at step 168, interface 124 is utilized to define linear program model

125 as described above. At step 170, linear program engine 122 determines a preferred solution for the project process based on the provided inputs. This preferred result is based on maximizing a desired criteria, which in this example is the internal rate of return of the project. At steps 172 and 174 the results are obtained and provided through interface 124 as output 140. The method concludes at step 182.

If the required design is a revamp scenario, the process is illustrated by reference numeral 176. At a step 178, information is gathered about the facility such as process units, yield information, operating conditions, bottlenecks, design capacities, and other relevant details of the plant. At a step 180, a model of the facility is customized and provided to linear program model 125. Customization refers to defining new process units or utilizing more accurate yield or operating data that may be available. Customization may also be performed for a grassroots model at step 180. Processing continues at steps 168, 170, 172, 174, and 182 for the revamp scenario in a similar manner to that of a grassroots design.

According to the present invention, a number of innovative modeling techniques are provided that enhance the speed and accuracy of system 120. These techniques are generally illustrated in FIGURE 3 as unique modeling techniques 136. Referring to FIGURE 4, these techniques include intermediate product pricing 510, energy integration 520, utility balances and integration 530, linear and nonlinear mathematical models to calculate yields and properties 540, estimates of capital costs and operating costs inclusive of inflation 550, and calculation

of major economic parameter project evaluation 560. These techniques are described in greater detail below.

One aspect of the invention utilizes intermediate product pricing 510 that contributes to more accurate modeling. The use of intermediate product processing is described below.

In conventional linear program models the user defines the feeds and products of the plant. The prices of the feeds and products are fixed and the linear program optimizer, such as linear program engine 122, cannot change the prices during optimization. One limitation of this conventional modeling is that if the product properties change due to modifications in processing schemes or component mix, the product price is not appropriately changed. Generally, the price of a product is dependent upon its properties.

A refinery or other similar processing facility generally produces finished products, such as syncrude 16, for market sale or intermediate products that serve as feeds to other process plants, or both. In order to select processing routes, feed and product prices are provided to a linear programming model. However, intermediate product quality often varies with each of the possible processing options. As an example, some refineries and upgraders produce a liquid blend such as synthetic crude. The quality of synthetic crude produced, such as sulfur, nitrogen, boiling range, gravity, etc. will depend upon the processing route used, and hence its value cannot be determined *a priori* and specified in a linear program model. To address this issue, according to the teachings of this aspect of the invention, linear program model 125 generates the price of intermediate products based on their

quality. Thus, according to the teachings of the invention the price of intermediate product streams is treated as a variable that is calculated by linear program engine 122. This allows varying the price of final products during optimization as the properties of the final products change.

As an example, a front-end unit consumes the primary raw material to produce three intermediate products, L1, L2 and L3. The qualities of these intermediate products are different from one another. These intermediate products can be transferred, for example, to a syncrude product blending unit or to another processing unit. Linear program model 125, to be run on linear program engine 122, is designed such that each unit in a model has the option to accept a feed stream from a number of possible upstream or downstream (as recycle) units, process the feed for sale to other units. Thus, by treating intermediate product price as a variable within the process model variations in the intermediate and final product price based upon variations in the underlying process may be incorporated, resulting in more accurate modeling. The use of such a modeling technique is graphically depicted by unique modeling techniques 136 in FIGURE 3.

According to this technique, internal buys and sells are tracked for each unit. The price of the syncrude product is internally calculated by considering the intermediate stream price and along with flow rates to, for example, the syncrude blend. The intermediate price equations developed are functions of stream bulk properties such as sulfur, nitrogen, specific gravity, conradson carbon residue, unsaturation content, etc. These equations, which are shown below, are developed by

considering the cost (capital, operating, profit margin etc. required for processing a given stream to finished product(s).

Linear programming models are used to maximize an objective function, which is normally the overall profit margin of the refinery, petrochemical plant, etc. The objective function can be expressed by the following formulae:

Objective Function = Sales - Purchases

An example of a formula used to price the intermediate stream follows:

$$\text{Price} = a_1*(P_1-P_{1b})+a_2*(P_2-P_{2b})+\ldots a_n*(P_n-P_{nb})$$

Where:

a_{1-n}=coefficient with units of $/property

P_{1-n}=property of stream

P_b=property base value

Once each stream has an associated price calculated, a unit price balance is established. This is achieved by charging each process unit for the input feed, and selling the output products to another unit. For example, a delayed coking unit is fed vacuum resid priced at one dollar a barrel. Linear program engine 122 internally calculates the price of the vacuum resid, and charges (subtracts) the cost of the resid from the objective function. The delayed coker liquid products (naphtha and gasoils) are then sold to the next unit (added to objective function), their price is also determined using the above formulae. If the gasoils are fed to a hydrocracker, this unit is charged the cost of this stream, so it subtracts this cost from the objective function. The gasoil stream has a balanced contribution to the objective function of zero.

Excerpts of the tables used to model the internal pricing structure are attached as Tables 1 through 4. These tables are SPDx (Price determination table "x" unit; SABx (Stream flowrate X Price table for "x" unit; PCALC (Calculated price is equaled to stream price); and SDCK (Process unit table).

Thus, in contrast to conventional linear program models, the user does not have to provide the price of one or more products of the plant, but rather such prices are treated as variables. The model will use the prices of the products that are provided and calculate the prices of those products for which prices are not provided.

Another aspect of the invention is optimization of energy utilization in the modeling process, depicted by reference numeral 520 in FIGURE 4. There are many processes where effective utilization of energy is key to an acceptable economic parameter for project implementation. Processes such as those available to convert gas to liquid products (GTL) are energy intensive. Their success and marketability depends on how effectively energy is integrated and managed.

Extending the use of linear program models for energy integration 520 saves significant time and effort. Conventional linear program models focus on material flow such as volume and mass; energy is used for the purpose of balancing the fuel consumption only. According to the present invention, energy streams are treated the same as material flow. Energy is treated the same way as mass flow but separated from mass as a distinct stream for specific utilization and integration matching the "producers" and "consumers" within the complex. Each process unit is assigned an "energy yield" structure. This allows energy

streams to consider many possible options, such as generating steam, creating electric power or use as a heating medium and select the most economically and thermally efficient route. Thus energy flow is represented as a variable, in linear program model 125, which is optimized by linear program engines. Therefore, efficient utilization of energy is considered as a factor in the optimization performed by linear program engine 122.

As an example, the effluent stream from a reactor is modeled as a mass effluent stream and a separate energy stream. This allows the "energy stream" to be directed into other process units that need energy, as a raw material, or sent to steam or power generation units. In a gas-to-liquid process, a very significant amount of energy stream is produced in the front end reforming unit that needs to be integrated with energy consumers in the processing complex and excess used for steam power generation. Effective energy integration between various process units and generation of export steam and/or power with the excess energy is a key for the success of gas-to-liquid processes.

Consider a reactor that receives a feed(s) with certain properties at a certain temperature. The reactor product(s) leave the reactor at a high temperature. This stream contains significant amounts of high level heat that can be recovered to improve the economics of the process. The economic feasibility of energy intensive processes such as Gas-to-Liquids and Integrated Gasification & Combined Cycle (IGCC) power generation, from refinery low valued products such as resid and coke, is dependent on effective energy recovery and utilization.

Described below is the energy integration implementation methodology according to the teachings of the invention for one such scenario. The concepts described here are general and are suitable for cases where energy integration is a consideration.

The GTL and IGCC processes typically have a front-end reactor (gasifer) to produce synthesis gas from: natural or associated gas, refinery resid streams, heavy oil feeds, and solid feeds such as Coal and petroleum coke. Air or oxygen is supplied as another feed.

The temperature of the feed(s) is an input in linear program model 125 and the feed characteristics such as carbon to hydrogen ratio, sulfur and nitrogen content, etc. can be inputs (external feed) or can be generated by the engine 122 (internal feed). The product, known as syngas, leaves the reactor at a very high temperature. This stream is an excellent source of very high level heat that can be recovered. The composition and heat contained in this reactor effluent stream is a function of temperature of the feed(s), feed properties, and reactor operating conditions (such as temperature).

The heat contained in the reactor effluent stream is:

$$QQr = \left[\sum m_i Cp_i\right](Ti - T_f)$$

Where T_i is the reactor exit temperature and T_f is the temperature to which the effluent stream should be cooled. The heat in the reactor effluent stream is split into many energy streams, as illustrated in FIGURE 7.

$$QQ1 = [\Sigma\ m_iCp_i](T_1-t_1)$$
$$QQ2 = [\Sigma\ m_iCp_i](t_1-t_2)$$
$$QQN = [\Sigma\ m_iCp_i](t_n-1-t_n)$$
$$QQF = [\Sigma\ m_iCp_i](t_f-1-T_f)$$

Latent heat of vaporization can also be added to the above sets of equations when phase change occurs during cooling. These energy streams are calculated by linear program engine 122. The number of energy cuts (QQ1, QQ2, ..., QQN) and their sizes (temperatures t_1, t_2, ...,) are predetermined by the user. These energy streams are calculated by linear program engine 122 and made available to other users in the form similar to that of a material stream.

FIGURE 8 illustrates an example reactor model 810. Reactor model 810 includes a reactor block 812, a gas cleaning unit 814, a gas turbine block 816, and a heat recovery steam generation block 818. The products from the reactor are illustrated in FIGURE 8 as: the reactor effluent-Mass stream; QQ1-Energy stream; QQ2-Energy stream; and QQN-Energy stream.

FIGURES 9A through 9C illustrate energy sinks made available for users of those heat sources. These are: cold streams requiring heating (preheating), stream generation, and final heat rejection to air or cooling water.

The methodology used to produce steam from this heat source is described below. The same approach can be extended for the other applications as well.

FIGURES 10A, 10B, and 10C illustrate an energy utilization scenario. The energy streams can produce high pressure steam 950, low pressure steam 952, and reject heat 954 to a cooling medium such as air or cooling water. The

954 to a cooling medium such as air or cooling water. The objective here is to determine an economically optimal way to distribute the available heat to these three energy sinks.

The heat recovered in the steam HP steam generator 956, Q_{HP}, is typically used for preheating boiler feed water, producing saturated steam, or superheating the saturated stream. Heat recovery is governed by the equation:

$$Q_{HP} = M_{HP-BFW} * H_{sf} + M_{HP} * H_{HP-VAP} + M_{HP} * H_{ss}$$

Where,

M_{HP-BFW} - Mass rate of the boiler feed water

M_{HP} - Mass rate of saturated high pressure steam

M_{HPS} - Mass rate of high pressure steam to be super heated

H_{HP-ss} - Specific enthalpy (ex: BTU/LB) required to super heat the steam

H_{HP-vap} - Specific enthalpy of vaporization (BTU/LB)

H_{HP-sf} - Specific enthalpy (ex: BTU/LB) required to super preheat the boiler feed water

The enthalpy values are either entered into the linear program model 125 by the user or can be calculated using formula or data interpolation. Here M_{HP-BFW}, M_{HP} and M_{HPS} can all be equal or different. The first term represents the sensible heat addition to heat the boiler feed water to the saturation temperature. The second term is the heat of vaporization required to convert saturated water to steam and the third term provides the heat required to super heat the saturated steam. Linear program engine 122 calculates the optimal values for M_{HP-BFW}, M_{HP} and M_{HPS} that satisfy the energy balance equation listed above, (A). A similar equation can be written for the low pressure steam 952 generation also.

Each of these energy streams have minimum T_1, T_2, ..., T_N) and average (T_{1m}, T_{2m}, ... T_{Nm}) temperatures associated with them. It is thermodynamically possible to exchange energy to a colder stream only if this temperature is greater than the cold stream temperature. For example, energy stream QQN can transfer heat to produce high pressure steam 950 only if:

$$T_N - T_{HP\text{-}Sat} >= T_{App}$$

Here T_{App} is specified in the linear program model 125. If this condition is not satisfied, then stream QQN will not be available for generating high pressure steam 950.

The cost of the steam generation is a function of the heat level and hence the temperature driving force available to it. A steam generator cost curve was generated and input into the linear program model 125 as described below in conjunction with the description of cost database 144. For a given case, linear program engine 125 calculates the cost using the following equation:

The steam generator cost =((QQ1*T1m + QQ2 * T2m + ..) /Base Duty)^n * TIC-Base. Here the value of "n" is typically between 0.6 - 1.0.

Linear program engine 122 performs a similar analysis for the steam generator and the final cooling steps and maximize the profit considering the operating costs and revenues generated by each of the blocks.

This approach can be applied to any scenario involving transferring heat from one source to another. The equations involved depend on the actual scenario.

Thus, energy flow is represented by variables in linear program model 125, allowing efficient distribution of energy to be considered as a factor in linear program engine 122 selecting an optimal process design.

Another aspect of the invention involves utility balances and integration 530, illustrated in FIGURE 4. Conventional linear program models developed for process plants do not include global balances for all utilities.

To facilitate description, conventional modeling techniques are described in detail below.

Step 1: In conventional linear program models developed for process plants, utilities requirements for every processing step are provided to calculate total utilities requirements. Also price for each of the utility (assuming that utilities purchased rather than produced within the processing plant) are provided in the model.

Step 2: While the linear program engine is running, total utilities requirement (ex: raw water, steam, cooling water, etc.) for the configuration is calculated. These requirements are then treated as if they are purchased rather than being generated within the plant (which is the actuality). In other words utilities are treated as operating costs (ex: quantity of steam required X cost per quantity of steam)

Step 3: Utility balances are performed outside of the linear program model to calculate the system sizes. Capital investment costs are then estimated for the utility systems using these developed system sizes.

Step 4: These capital investment costs are added to those of the processing unit investment costs to develop the total capital costs. This is used to determine the project internal rate of return (IRR) and to compare with alternate scenarios.

Thus conventionally, utility balances are performed outside of the model manually and a cost factor applied to determine investment cost. This approach, in general, is

very time consuming and does not allow the user to look at the overall picture to perform a global optimization. Further, this approach is inaccurate and results in an unreliable forecast of investment costs as a result of building excessive design factors in the utility systems to account for the uncertainty in the estimate.

According to the present invention, performing utility balances within the framework of the process plant linear program model, such as linear program model 125, addresses the drawbacks of the conventional approach. The utility balance approach is illustrated in FIGURES 11 and 12.

A process 230 of FIGURE 11 includes process units 244, water systems 246, fuel gas system 250, and substation 252. According to a utility balance approach, utility inputs and outputs of each of these process units is balanced. Thus, inputs including water 234, natural gas 236, and power 238 are balanced with outputs of associated process units. Thus, the fact that some process units generate utilities is considered. Those outputs include process water 254, steam 256, cooling water 258, fuel gas 260, and power 262. Major utility requirements for all the processing units are input into linear program model 125. Linear program engine 122 then performs a balance to estimate the capacity requirements for each of the utility systems and calculates the net purchases required from outside sources. For example, a water balance is performed considering the process water usage and steam and cooling water blow downs to estimate the net water requirements. A similar balance approach is used for fuel gas and power as well. This approach allows linear program engine 122 to estimate capital costs for the utility systems suitable for comparison purposes and operating costs for the purchase of

utilities such as raw water, natural gas and power from outside sources. Capital cost curves are stored in the LP model 122.

Thus, according to the teachings of this aspect of the invention, the generation of utilities by process units is taken into account in determining net utility requirements. This allows the size of utility units to be treated as a variable in linear program model 125. Based on the calculated size of each utility unit accurate investment cost estimates may be made that takes into account the economics of scale. A detailed step-by-step approach for utility balances is described below for one embodiment of the invention with reference to FIGURE 12, which illustrates utility users and producers for an example manufacturing process.

Step 1: Major utility requirements for all the processing units are input into linear program model 125.

Step 2: Linear program engine 122 calculates the net steam requirements for a configuration, according to the following formula.

Net HPS Reqd. = HPS Reqd. for process units - HPS produced in process units.

Net MPS Reqd. = MPS Reqd. for process units - MPS produced in process units.

Net LPS Reqd. = LPS Reqd. for process units - LPS produced in process units where, HPS, MPS and LPS indicate high, medium and low pressure steams respectively. The concept is easily extended to any number of steam levels.

Step 3: The net steam required should be supplied by the steam generation system. The steam boilers of the steam generation system generate steam only at the highest level required. The high pressure steam is then let down

to medium and low pressure steams to satisfy their requirements. This converts the steam balance as follows:

Net HPS Reqd. =

HPS Reqd. for process units- HPS produced in process units = HPS letdown to MPS + HPS letdown to LPS

Net MPS Reqd. = 0 =

MPS Reqd. for process units - MPS produced in process units = MPS created via, HPS to MPS letdown

Net LPS Reqd. = 0 =

LPS Reqd. for process units - MPS produced in process units + LPS created via HPS to LPS letdown + LPS created via MPS to LPS letdown

Linear program engine 125 then calculates the normal operating capacity of the steam generation system using the above equations.

Step 4: The boiler feed water (BFW) requirement is then calculated using:

Net BFW=

Total BFW required in the processing steps+
Total Blow Down from all steam producers

The BFW system receives treated raw water from the raw system and converts it into BFW to satisfy the requirement. This determines the operating capacity of the BFW System.

Step 5: The size of the cooling water (CW) system is determined by: Net CW=Total cooling water required in all of the units. This determines the operating capacity of the CW System.

Step 6: The wastewater treatment (WWT) system unit capacity is determined by: WWT Requirement = Blow Downs from Steam Generators + Blow Down from Cooling Water System

+ All Process Waste Waters + Storm Water. This determines the operating capacity of the WWT System.

Step 7: The raw water treatment (RWT) system unit capacity is determined by: RWT Requirement = Total Process Water Requirements of all units + Makeup to Cooling Water System + Makeup to BFW System + Other Requirements This determines the operating capacity of the RWT System.

Step 8: The calculated unit capacities are then used along with the individual system over design factors and cost curves to determine the investment costs for each of the utilities systems.

Thus, according to the teachings of the invention, the utility balancing approach allows linear program engine 122 to consider the investment costs for all of the utility systems in the determination of optimal processing route. This approach eliminates the tedious and time consuming approach used by the conventional linear program models. The above concept can be easily extended to other utility systems also.

According to another aspect of the invention, linear and non-linear mathematical models 540 illustrated in FIGURE 4, are utilized to calculate yields and properties of the yields. Linear programming models model only linear systems. However, actual processes are often non-linear. Such systems are typically linearized for the purpose of modeling. Linearization limits the range of usefulness of a model, and the user should be aware of such model limitations. Smart interconnected spreadsheet modeling is utilized according to one embodiment of the invention to address this problem.

To facilitate description, the use of smart interconnected spreadsheet 142 modeling is described in the

context of an example involving "deep deasphalting" of vacuum residue of an extra-heavy crude oil using a solvent. The objective of this process is to recover oil from the vacuum residue by using light solvents such as propane, butanes, pentanes, or a mixture of solvents. The solvent is recovered and recycled back to the process. The two major liquid products from this process are the deasphalted oil (DAO) and asphalt.

In order to model this process using linear programming, linear correlations are necessary to predict the yield and product properties. Deasphalted oil yields are typically obtained by performing lab tests. A correlation is used to estimate deasphalted oil yield as a function of feed properties such as specific gravity. The properties of deasphalted oil, such as specific gravity, sulfur, nitrogen, conradson carbon and metals are non-linear functions of the deasphalted oil yield. This is difficult to model using conventional techniques.

According to the present invention, a smart spreadsheet 142 is used to predict the yield and product properties for this unit. This spreadsheet, the content of which is illustrated in Table 5, calculates the vacuum residue feed properties for the selected crude feed, calculates the yield and product properties, and updates linear program model 125. This modeling technique also allows the user to replace the estimated values by licensor values, when available. This may be extended to model some of the other process units also.

Another aspect of the invention involves estimation of operating costs and capital costs 550. Major operating cost parameters such as utilities, catalyst and chemical cost, running royalty, operating labor, maintenance,

insurance and taxes are included in linear program model 125.

Since the modeling concept described above includes performing complete balance of the utilities to develop the utility system sizes such as steam generation, cooling water, etc., only those items such as raw water, power, fuel gas, etc. need to be purchased from outside the processing plant. These utility purchases are included as a component of the operating cost. Conventional modeling techniques do not perform utility balances. The utilities that are typically created within a processing plant such as steam, cooling water, etc. are treated as a part of the operating costs. This is typically resolved using a time consuming external utility balancing step.

Information regarding catalyst and chemicals requirement, running royalty, and operating labor is gathered for all of the processing steps and converted into cost database 144.

Maintenance and insurance are used as certain percentages of the Total Investment Cost. Tax rates are based on the region and are also included in the costs.

The cost of the imported utility streams is one of the components of the operating costs. The utility balance approach described above helps to determine the actual utilities to be imported for a processing unit. Purchase price for each of the utility streams such as that for raw water, etc. is provided to linear program model 125. Linear program model 125 uses the internal utility balance and the pricing information to calculate this component of the operating costs.

Capital cost information for each unit and system considered is useful to arrive at a preferred solution.

The conventional way to determine the Rough Order of Magnitude Total Investment Cost of a project is to develop a cost curve, that is a nonlinear function of the unit capacity.

FIGURE 13 shows example cost curves generated according to both conventional methods and according to the present invention. Conventional cost curves are determined by obtaining the cost of the unit for a base capacity and then fitting an exponential curve that passes through the base point (Figure 13). As shown by curve 274 in FIGURE 13, conventional cost curves developed using this approach are non-linear but smooth.

Cost curves are functions of the unit size, operating severity, geographical location and process complexity. The cost estimate using the conventional method is not realistic as it does not reflect the minimum feasible unit size and step change in cost due to the need to use multiple trains when single train maximum capacities are exceeded. Thus the existing cost curve modeling methods may not find the optimal solution.

According to the present invention, an innovative methodology and modeling system is utilized for a more complex investment cost curve format to be incorporated, as shown in FIGURE 13. This method allows the model to predict more accurate capital costs taking into consideration the minimum feasible unit size and maximum capacities. The cost curves 276 developed are not continuous like conventional ones, instead they have breaks 272 wherever the maximum capacity of the unit is exceeded and a second train is required. The minimum capacity constraints are modeled by assigning a minimum capital cost 270 for all capacities below the constraint. This

discourages linear program engine 122 from choosing unrealistic processing schemes.

Conventional linear programming models used in the process industry use an operating stream day basis. Thus all the utilities consumed are based on the actual flowrate of the stream through the unit. Designers on the other hand must build a process unit to be able to accommodate the maximum flowrate that could potentially flow through the unit. These flowrate peaks may be due to emergency shutdowns, changes in feed properties, etc. Thus a design margin is usually added to the operating flowrate and the investment cost of the unit should be estimated for this higher capacity.

The conventional way to determine the Rough Order of Magnitude (ROM) Total Investment Cost (TIC) of a project is to develop a cost curve, that is a nonlinear function of the unit capacity. These curves are determined by obtaining the cost of the unit for a base capacity, and then fitting an exponential curve that passes through the base point. The curve is smooth but non-linear. The cost curve is a function of the unit size, operation severity, geographical location and process complexity. The drawback of using the conventional method is that the curve built is a function of the base cost and exponent input into the model only.

To obtain the TIC using this method the following equation is used:

TIC = [(Operating Capacity/Base Capacity) ^ (Exponent)] * Base TIC. The value of the exponent is typically in the range of 0.6 to 1.0.

This makes the linear program engine:

- Predict use of unreasonably small size processing unit.
- Not recognize physical size limitation of a unit (need to use multiple trains).
- Ignore all the additional factors contribute significantly towards the total investment costs.

As a result of these issues the conventional LP models will predict erroneous results.

According to the teachings of the invention, linear program model 125 is developed to accurately model the capital investment costs of all the units with the additional design margins that would at the same time not modify the actual utilities required. This is done through the use of factors that would modify the TIC to create a pseudo-TIC. This method allows the model to adjust the capital cost charge due to different operation severities, exceeding maximum process capacity constraints, and multiple trains. An additional feature is that the model has built-in minimum unit capacities, in order to discourage the linear program engine 122 from choosing unrealistic processing schemes. The cost curves developed are not smooth like conventional ones, instead they have breaks in them wherever the maximum capacity of the unit is exceeded and a second train is required. The minimum capacity constraints are modeled by assigning a minimum capital cost for all capacities below the constraint.

Additional features found within linear program model 125 are inflation factors and specific site cost factors. These features expand and applicability of the model to different geographic locations and time frames, since the base curves were developed for a specific location and year.

Detailed Description of Cost Curves:

1. **Capital Charge (CC):** Many linear program models are designed to be used on a daily basis and to optimize the daily operations of a plant or refinery. It is because of this that the capital cost of any new units or a whole grassroots facility must be entered into the matrix as a capital charge per day. This capital charge is introduced into the objective function and thus the investment required for the new units is optimized. To properly introduced the capital charge to the linear program model 125, the Total Investment Cost must be divided by the number of years required by the user to recover the capital investment, and by the number of days in one year that the facility is in operation.
2. **Overall Onstream Factor (OOF):** The ratio between the number of operating days of the whole facility and 365 (number of days in one calendar year).
3. **Unit Onstream Factor (UOF):** Each process unit may have its respective onstream factor. This factor is a measure of how reliable a process is and how much downtime is required for activities such as periodic clean-up of certain key equipment, shutdowns of units for maintenance. This factor may be different from the overall onstream factor.
4. **Design Factor (DF):** A process unit may be designed with a margin above the normal operating requirements to accommodate for uncertainty in any of the design parameters. This additional margin is defined as the design factor.
5. **Multiple Trains (MT).** Certain process units may be critical for the operation of the overall facility.

These units are generally designed to have an additional train, to serve as a spare. An example of such a unit is the stream generation unit, common practice is to provide two spare steam boilers.

6. **Inflation Factor (IF):** The database developed for the model uses as a basis the fourth quarter of 1998. To adjust the TIC for construction in a different year an inflation adjustment is required.

7. **Miscellaneous Factor (MF):** The model incorporates within the overall TIC a factor for additional costs which are dependent on the size and complexity of the process units. Examples of the systems that are priced in this manner are the distributed control system, fire water system, ISBL/OSBL piping, and flare system, etc.

8. **Site Location Factor (SLF):** The process units TIC is estimated for construction in the U.S. Gulf Coast. The actual plant may be built elsewhere and labor rates, and freight expenses, etc., are different to those at the U.S. Gulf Coast. An adjustment is required for changing the construction site.

The methodology used to developed the capital cost curves 135 for use in linear program model 125 are described below:

The additional factors, described above, are provided to an LP cost curve sub-model when the user makes any changes and automatically updated within the program through smart links 126. The pseudo-TIC is obtained using the following equations:

Design Margin Factor (DMF)=(DF*OOF/UOF)^ (Exponent) (1)

Pseudo Base TIC (Base TIC')=(Base TIC)*DMF*SLF*MF*IF (2)

Pseudo TIC (TIC')=MT*[(Capacity/Base Capacity)^(Exponent)]

*Base TIC'

Here the value of the exponent is typically in the range of 0.6 - 1.0.

The capital charge curves are generated using:

CC=TIC'/(# Years * # Operating Days)

CC coefficient = CC / Capacity

CC coefficient curves as a function of capacities are then developed for use in the linear program model 125. An example cost curve that is stored as a part of the linear program model 125 is provided below:

XUN1 (Used by LP)	Capacity /Day, MBD	0	0.01	5	5.5	10	40	60	60.5
YUN1 (Used by LP)	CC Coeff.	56639	5663.9	11.33	10.98	9.01	5.7	4.99	5.24
This row is for outside LP calculation only	Total Inv. Cost, MM$	78.558	78.558	78.558	83.738	124.99	316.42	415.18	439.409
		Min. size unit			One Train Region				Two train Region

The cost curves thus generated are stored in linear program model 125. When linear program model 125 is executed, linear program engine 122 will create configurations for selecting optimal processing route. Linear program engine 122 will then determines the normal operating flow rate, XUN1, for each of the processing step. It then looks-up in the cost curve and estimate the capital charge coefficient, YUN1, (CC Coeff.) for each of the units. This factor will then multiply the operating flow rate to determine the total capital charge for a unit. The total capital charges of all the units are summed to get the grand total capital charge. These costs are used in the LP objective function to determine the optimal processing route.

FIGURE 14 is a flow chart illustrating the generation of cost database 144. The steps involved in the development of a cost database 144 suitable for use in system 120 are outlined here.

At a step 202, investment cost and capacity information for all processing blocks that might be utilized are gathered. Each data set consists of total investment cost, base year and geographical location for a processing block (such as crude distillation, delayed coking, etc.). At a step 204, a determination is made of whether the collected data utilizes a Gulf Coast Basis. If not, the collected total investment cost information is converted to a Gulf Coast Basis using specific conversion factors at a step 218. The investment cost is then converted to the base year, e.g. 1998, using the Nelson Cost Index (NCI).

Paid-up royalty charges for licensor units and initial catalyst costs are added to the capital cost at step 208. A running royalty is considered as an operating cost.

Investment cost data is grouped based on the type of processing block. Plots of the investment cost versus capacity are prepared for each processing step at step 210. All ambiguous data points observed in these plots are discarded. A curve, as shown in FIGURE 8, is developed for each of the processing blocks. Key factors such as minimum feasible size of the unit, maximum train capacity, investment cost impact due to the severity of operation, unit onstream and design factor are considered in developing the cost curves. The developed curves are then converted into data tables for use in the model.

All the capital cost versus capacity table information is converted into Flow versus $/Flow at step 212. Details of this conversion are described below. The capacity of a processing block is expressed as: Capacity = Flow / Time. In a process plant application, linear program models are typically used for maximizing the revenue. A time frame such as a day, or a month, or a year is selected to compute the revenue (example: $ per day). To avoid dealing with very large or very small numbers, process oriented industries such as refineries and petrochemical complex models typically use one day as the time frame. The revenues calculated by the model are used in further economic analysis to calculate the net profit in dollars per year or internal rate of return.

The objective function optimized by system 120 is internal rate of return as measured by revenue per day. That means all the internal calculations, with the exception of the overall economic analysis, are typically

performed on a per day basis. The objective function that the LP model will maximize is as follows: Revenue($/day) = Sales($/day) - Expenditure($/day). In order to incorporate the capital investment cost in this equation.

Revenue($/day) = Sales($/day) - Expenditure($/day) - Capital Recovery($/day).

The capital investment cost is converted into "$/Flow" cost for all of the processing blocks using the following equation:

$$\$/Flow = \frac{TIC\ of\ the\ unit\ (\$)}{Capital\ Recovery\ Period}$$

where the capital recovery period is in years and capacity is expressed in Flow/day.

This $/Flow capital recovery cost when multiplied by the respective unit capacity in Flow/day results in the capital recovery cost expressed in $/day for that processing block. The total capital recovery ($/day) is a sum of capital recovery charges for all the processing blocks, utilities and other capital investment components.

The capital recovery period is a direct input to the model. Alternately, this can be calculated for a desired internal rate of return (IRR) using the help facility 416, FIGURE 5.

Capital recovery costs for utility systems such as steam, cooling water, fuel gas, etc. are developed in the same manner as the process units at step 214, and capital recovery costs for miscellaneous utility and offsite units such as Fire Water System, Relief System, Process & Instrument Air and Power Distribution are calculated and

expressed as a fraction of the total process unit costs at step 214.

The total investment costs for various types of tanks (fixed roof, floating roof, spheres, heated tanks, etc.) are collected. These costs are then converted into $ TIC /BBL cost for the base year of 1998 on the Gulf Coast basis. Instead of using a fixed $/BBL value for all the capacity ranges, a cost curve can also be used to estimate the tankage cost. The $/BBL investment cost is converted into $/BBL capital recovery cost, also at step 214.

The Total Investment Cost allowances for the following systems are also provided at step 214 as a fraction of the total processing unit costs, which are ISBL/OSBL, Infrastructure (Buildings and Sitework), Solid and Liquid Handling. Inclusion of all the major costs in the optimization process eliminates additional external steps and iterations required for developing an optimized processing configuration.

A table of overall Nelson Cost Index is compiled and used to convert the investment costs to any year of interest automatically at step 216.

Factors are developed for every capital cost component to convert from Gulf Coast to another basis. This may be easily extended to convert the capital costs into any other Geographical location automatically.

In order to evaluate the economic feasibility of a project or to compare different configurations it is important to use an economic analysis model. Key parameters such as the capital investment cost, operating costs, project life, tax structure, etc. are required for the economic model. This step in the conventional approach is an external step. Integrated modeling treats this economic

model as an integral portion of the model and allows automatic download of the necessary economic parameters to estimate the internal rate of return (IRR). The economic parameters can also be directly transferred to any external economic model.

Referring to FIGURE 4, the use of modeling techniques 510, 520, 530, 540, 550, and 560 allow for more rapid and more accurate optimization of a process design.

FIGURES 15A, 15B, and 15C illustrate alternative processing steps for the system shown in FIGURE 1A that were generated and compared with each other by the system of FIGURE 3. The generation of these alternative processes and the selection of the best alternative is described below.

The input required such as, crude feed, feed rate, syncrude specification and economic parameters were entered into the model using spreadsheets 410 of interface 124. User interface 124, in turn, generated a linear program model 125. Linear program model was then executed.

Results such as, block flow diagram with stream flows, utilities summary, unit capacities and ROM capital cost breakdown (Table 6) and overall economic analysis (Table 7) were updated automatically from the output report 130.

System 120 selected process 300, which includes carbon rejection followed by secondary hydroprocessing as the preferred method (Case 1; FIGURE 15A) for this scenario. A block diagram of this process is illustrated in FIGURE 15A and includes distillation step 304, carbon rejection step 308, and secondary hydroprocessing step 312 to result in syncrude 314 from diluted crude 302. Next, the model was used to run other predetermined alternate cases to verify the solution obtained. Two such cases are described here.

Case 2 (process 320; FIGURE 15B) consisted of residual thermal cracking followed by carbon rejection 328 as the primary upgrading option with secondary hydroprocessing 312 to produce syncrude. Case 3 (process 340) utilized residual hydroprocessing 350 and carbon rejection 354 in parallel as the primary upgrading routes in addition to secondary hydroprocessing step 312 to produce syncrude 362 (FIGURE 15C). The results are summarized in Table 8. As shown in Table 8, case 1 was better than cases 2 and 3.

For a given feed and throughput, the actual quantity and quality of synthetic crude produced is dependant on the route selected. Since the quality of synthetic crude varies with the upgrading route it is difficult to assign a value ($/BBL) for it before its quality is determined. However, conventional linear program methods require a price to be assigned to the syncrude in order for the model to perform a global optimization. Further, conventional linear program models lack a capital cost structure and also do not have the cost components defined with enough accuracy to perform studies of this nature. Due to the above reasons, conventional method would have taken significantly more time and effort and hence would have required more money to solve this complex problem.

Although the present invention and its advantages have been described in detail, it should be understood that various changes, substitutions, and alterations can be made therein without departing from the spirit and scope of the present invention as defined by the appended claims.

TABLE 1: PRICE DETERMINATION OF UNIT2 DELAYED COKER PRODUCTS

*SPD2

	TEXT	DCN	U21	G11	S11	C11	B11
*DELAYED COKER NAPHTHA PRICE DET.							
EVOLdcn	CAPTURED ACTIVITY	1					
RBALU21	BALANCE ROW	-1	1				
ESPGU21	SPG OF UNIT2 PROD1	-999		1			
ESULU21	SUL OF UNIT2 PROD1	-999			1		
ECONU21	CON OF UNIT2 PROD1	-999				1	
EBLDU21	BLD OF UNIT2 PROD1	-999					1
ECNTU21	CNT OF UNIT2 PROD1	-999					
*			***Formulae Coefficients***				
RAMBU21	PRICE OF PROD1		999	a	b	c	d

TABLE 2: COLUMN ACTIVITY MULTIPLICATION TABLE FOR UNIT2

*SAB2

	TEXT	U21
*	PRODUCT 1	1
EVOLDCN	CAPTURED ACTIVITY	1
EAMBP21	PRODUCT 1 SALE	-999

TABLE 3: PROPERTY CALCULATIONS

	TEXT	SPG	SUL	CON	NIT	BLD	AMB	OLE
*INTERMEDIATE FEED PRICING								
DCUNU21	DCN IN TERMS OF U21						1	

TABLE 4: LP TABLES

TABLE	TEXT	BAS	SUL	SPG	DFP	P21	P22	P23
VBALDCX	VACUUM RESID							
VBALHYD	HYDROGEN	-0.0080		-0.0006				
VBALH2S	H2S	-0.0253	0.0015					
VBALNC1	METHANE	-0.0866		-0.0054				
VBALC2=	ETHYLENE	-0.0095		-0.0007				
VBALNC2	ETHANE	-0.0561		-0.0039				
VBALC3=	PROPYLENE	-0.0168		-0.0012				
VBALNC2	PROPANE	-0.0367		-0.0025				
VBALC4=	BUTYLENES	-0.0164		-0.0012				
VBALIC4	ISO-BUTANE	-0.0045		-0.0003				
VBALNC4	N-BUTANE	-0.0190		-0.0013				
VBALDCN	COKER NAPHTHA	-0.1598		-0.0003				
VBALHCN	HEAVY COKER NAPH.	-0.0466		0.0016				
VBALLCG	COKER LIGHT GASOIL	-0.2382		0.0011				
VBALHCG	COKER HEAVY GASOIL	-0.2143		0.0376				
VBALCOK	PROCESS COKE, MTONS	-0.0565		-0.0010				
	BALANCE CHECK	-0.9299	0.0015	0.0236				
UBALDFP	DCK FEED COST				1			
UBALDCN	DCN SALES					-1		
UBALHCN	HCN SALES						-1	
UBALLCG	LCG SALES							-1
UBALHCG	HCG SALES							
CAPTURE PRODUCT ACTIVITIES								
EVOLDCN	COKER NAPHTHA	-0.1598	0.0000	-0.0003				

TABLE	TEXT	BAS	SUL	SPG	DFP	P21	P22	P23
EVOLHCN	HEAVY COKER NAPH.	-0.0466	0.0000	0.0016				
EVOLLCG	COKER LIGHT GASOIL	-0.2382	0.0000	0.0011				
EVOLHCG	COKER HEAVY GASOIL	-0.2143	0.0000	0.0376				
EVOLdcn	COKER NAPHTHA	-0.1598	0.0000	-0.0003				
EVOLhcn	HEAVY COKER NAPH.	-0.0466	0.0000	0.0016				
EVOLlcg	COKER LIGHT GASOIL	-0.2382	0.0000	0.0011				
EVOLhcg	COKER HEAVY GASOIL	-0.2143	0.0000	0.0376				
EAMBP21	PRODUCT 1 SALE					1		
EAMBP22	PRODUCT 2 SALE						1	
EAMBP23	PRODUCT 3 SALE							1
EAMBP24	PRODUCT 4 SALE							
EAMBDCK	FEED COST					1		

TABLE 5: DEEP DEASPHALTING UNIT YIELD AS DEFAULT DATA

FEED DESCRIPTION	Model REC	Licensor Info
Std. Spgr	1.073	1.073
°API	0.37	0.37
Nitrogen, wt %	0.74	0.74
Sulfur, wt %	6.55	6.55
Concarbon, wt %	26.03	26.03
Nickel, ppmw	111.3	111.3
Vanadium, ppmw	524.7	524.7
Viscosity @ 210°F		
Viscosity @ 275 °F		
Deasphalted Oil		
Yield, wt%	52.2	
Yield, vol %	55.8	
Std. Spgr	1.0047	

°API	9.34
Nitrogen, wt %	0.30
Sulfur, wt %	4.24
Concarbon, wt %	14.39
Nickel, ppmw	5
Vanadium, ppmw	146
Viscosity @ 210 °F	
Viscosity @ 275 °F	
Viscosity @ 450 °F	
Viscosity @ 550 °F	

Asphaltenes

Yield, wt%	47.8
Yield, vol %	44.2
Std. Spgr	1.1594
°API	-9.45
Nitrogen, wt %	1.23
Sulfur, wt %	9.08
Concarbon, wt %	38.8
Nickel, ppmw	228
Vanadium, ppmw	939
Viscosity @ 210 °F	
Viscosity @ 275 °F	
Viscosity @ 450 °F	
Viscosity @ 550 °F	

TABLE 6: UNIT CAPACITY & ROM COST

UNIT	CAPACITY	UNIT	TIC MM$
PROCESS UNITS			**705.2**
ATM. DIST. UNIT	136623	BPSD	56.0
VACUUM DIST. UNIT	85200	BPSD	41.9
DELAYED COKER	0	BPSD	0.0
RESID HYDRO-PROCESSING	48061	BPSD	256.6
CANMET/HDH UNIT	0	BPSD	0.0
RESID THERMAL CRACKING	0	BPSD	0.0
VACUUM RESID DESULFURIZATION	0	BPSD	0.0
ROSE DEASPHALTING	0	BPSD	0.0
NAPHTHA/LGO HYDROTREATER	0	BPSD	0.0
RESID FLUID CAT CRACKER	18311	BPSD	72.9
HGO HYDROTREATER	0	BPSD	0.0
HYDROCRACKER	32800	BPSD	76.9
GAS RECOVERY PLANT	11624	BPSD	20.1
AMINE REGENERATION	5953	GPM	16.3
SULFUR PLANT	685	MTON/D	80.0
SOUR WATER STRIPPING	500	GPM	19.4
HYDROGEN PLANT	95	MMSCFD	65.0
UTILITIES			**95.2**
STEAM GENERATION	0	MTON/D	0.0
RAW WATER TREATMENT	207	M3/hr	9.2
COOLING TOWER	6625	M3/hr	15.8
ELECTRIC POWER DIST.	0.032		22.57
FUEL GAS SYSTEM	4943	MMBTU/hr	5.2
INST.AIR & NITROGEN	0.02		14.10

FIRE WATER SYSTEM	0.01		7.05
DSC	0.03		21.16
OFFSITES/MISC.			**160.51**
DILUTED CRUDE STORAGE	3	DAYS	9.63
DILUENT STORAGE	3	DAYS	0.00
SYNCRUDE STORAGE	600	MBLS	13.44
LPG STORAGE	5	DAYS	17.51
HOT RESID STORAGE	10	MBLS	3.92
UNTRTED NAPHTHA STORAGE	10	MBLS	0.46
LGO STORAGE	1	DAYS	1.10
SOLIDS HANDLING	685	MTON/D	0.00
WASTE WATER TREATMENT	169	M3/hr	15.7
INFRASTRUCTURE	0.08		56.41
ISBL/OSBL ALLOWANCE	0.05		35.26
LIQUID HANDLING	0		0.00
RELIEF SYSTEM	0.01		7.05
MISCELLANEOUS			0.00

TABLE 7: OVERALL ECONOMIC ANALYSIS

1.0 CAPITAL COST		**TIC (MM$)**
<u>**UNITS**</u>		
PROCESS UNITS	$	705.17
UTILITIES	$	95.15
OFFSITES/MISC.	$	160.51
TOTAL ROM INVESTMENT	$	960.83
2.0 PURCHASE/SALES		
SYNCRUDE PRODUCTS	$	683.01
CRUDE + OTHER RAW MATL	$	(247.28)
OPERATING COSTS	$	(78.52)
COST ADJUSTMENTS	$	(7.85)
GROSS REVENUE	$	349.36
3.0 ECONOMIC PARAMETERS		
COST BASIS		Venezuela
CAPITAL RECOVERY		20
DEPRECIATION		Straight Line
TAXES, %		42
PROJECTED IRR		17.2%

TABLE 8: UPGRADER CASE COMPARISON

CASE NO.	TIC (MM$)	IRR(%)
CASE1 (Carbon Rejection)	*810*	*18.0*
CASE2 (RTC/Carbon Rejection in Series)	862	15.6
CASE 3 (RHP/Carbon Rejection in Parallel)	1122	11.4

CASE 1 WAS SELECTED BY RAYTHEON'S LP MODEL AS THE ECONOMICALLY OPTIMAL CASE

WHAT IS CLAIMED IS:

1. A computerized system for facilitating design of a manufacturing process system having a plurality of process units, the system comprising:

a processor;

a memory accessible by the processor;

a linear program model forming a plurality of linear equations describing constraints on the manufacturing process system, the linear equations including, as variables, price information associated with at least one input product and at least one output product of at least one of the process units; and

a linear program engine stored on the memory and operable to be executed on the processor and further operable to generate an optimal solution for the plurality of linear equations.

2. The computerized system of Claim 1, and further comprising a plurality of databases in communication with the linear program model for storing information associated with each process unit.

3. The computerized system of Claim 2, and further comprising an interface for providing the stored information from the plurality of databases to the linear program model for execution by the linear program engine.

4. The computerized system of Claim 3, wherein the interface comprises at least one macro for automatically updating the linear program model with information stored in the plurality of databases.

5. The computerized system of Claim 1, wherein the linear program model comprises a plurality of spreadsheets.

6. The computerized system of Claim 1, wherein the linear equations further include, as variables, energy flow information associated with at least one of the process units.

7. The computerized system of Claim 1, wherein the linear equations further includes, as variables, investment cost information associated with utility requirements of at least one of the process units.

8. The computerized system of Claim 2, wherein the plurality of databases comprises at least one database comprising linearized information for at least one variable associated with the plurality of linear equations and further comprising an interface operable to automatically provide a linearized data point to the linear program model.

9. A computerized system or facilitating design of a manufacturing process system having a plurality of process units, the system comprising:

a processor;

a memory accessible by the processor;

a linear program model forming a plurality of linear equations describing constraints on the manufacturing process system, the linear equations including, as variables, energy flow information associated with at least one input product and at least one output product of at least one of the process units; and

a linear program engine stored on the memory and operable to be executed on the processor and further operable to generate an optimal solution for the plurality of linear equations.

10. The computerized system of Claim 9, and further comprising a plurality of databases in communication with the linear program model for storing information associated with each process unit.

11. The computerized system of Claim 10, and further comprising an interface for providing the stored information from the plurality of databases to the linear program model for execution by the linear program engine.

12. The computerized system of Claim 11, wherein the interface comprises at least one macro for automatically updating the linear program model with information stored in the plurality of databases.

13. The computerized system of Claim 9, wherein the linear program model comprises a plurality of spreadsheets.

14. The computerized system of Claim 9, wherein the linear equations further include, as variables, investment cost information associated with at least one of the process units.

15. The computerized system of Claim 9, wherein the linear equations further include, as variables, the site of external utility units associated with utility requirements of at least one of the process units.

16. The computerized system of Claim 10, wherein the plurality of databases comprises at least one database comprising linearized information for at least one variable associated with the plurality of linear equations and further comprising an interface operable to automatically provide a linearized data point to the linear program model.

17. A computerized system or facilitating design of a manufacturing process system having a plurality of process units, the system comprising:

a processor;

a memory accessible by the processor;

a linear program model forming a plurality of linear equations describing constraints on the manufacturing process system, the linear equations including discrete capital cost information for at least one of the plurality of process units, the discrete capital cost information including data representing quantified capital costs associated with redundant process units; and

a linear program engine stored on the memory and operable to be executed on the processor and further operable to generate an optimal solution for the plurality of linear equations.

18. The computerized Claim 17, wherein the linear equations include, as variables, price information associated with at least one input product and at least one output product of at least one of the process units.

19. The computerized system of Claim 18, wherein the linear equations further include, as variables, energy flow information associated with the at least one input product and at least one output product of at least one of the process units.

20. The computerized system at Claim 19, and wherein the linear equations further include, as variables energy flow information associated with at least one of the process units.

21. The computerized system of Claim 20, wherein the linear equations further include, as variables, the size of external utility units associated with utility requirements of at least one of the plurality of process units.

22. The computerized system of Claim 21, and further comprising a plurality of databases in communication with the linear program model for storing information associated with at least one of the process units.

23. The computerized system of Claim 22, and further comprising an interface for providing the stored information from the plurality of databases to the linear program model for execution by the linear program engine.

24. The computerized system of Claim 23, wherein the interface comprises at least one macro for automatically updating the linear program model with information stored in the plurality of databases.

25. The computerized system of Claim 24, wherein the linear program model comprises a plurality of spreadsheets.

26. The computerized system of Claim 25, wherein the plurality of databases comprises at least one database comprising linearized information for at least one variable associated with the plurality of linear equations and wherein the interface is further operable to automatically provide a linear data point to the linear program model.

27. A computerized method for designing a manufacturing process having a plurality of units, the method comprising:

providing to a linear program engine data representing a plurality of linear equations describing constraints on the manufacturing process, the linear equations including, as variables, price information associated with an input and an output of at least one of the plurality of units;

optimizing, based on a predetermined criteria, the linear equations by the linear program engine; and

in response to the optimization, generating a description of the manufacturing process.

28. The method of Claim 27, wherein optimizing, based on a predetermined criteria, comprises optimizing based on the internal rate of return of the manufacturing process.

29. The method of Claim 27, wherein providing data representing the linear equations further comprises providing data representing a plurality of linear equations that include energy flow information for at least one of the plurality of units as variables.

30. The method of Claim 27, and further comprising automatically accessing at least one database to generate the data representing the plurality of linear equations.

31. The method of Claim 27, wherein providing data further comprises providing data stored in a plurality of spreadsheets.

32. The method of Claim 30, wherein automatically accessing at least one database comprises automatically accessing at least one by a spreadsheet macro.

33. The method of Claim 29 wherein providing data representing a plurality of linear equations further comprises providing data representing a plurality of linear equations having, as a variable, investment cost information associated with at least one of the process units.

34. A computerized method for designing a manufacturing process having a plurality of units, the method comprising:

providing to a linear program engine data representing a plurality of linear equations describing constraints on the manufacturing process, the linear equations including, as a variable, energy flow information associated with at least one of the plurality of units;

optimizing, based on a predetermined criteria, the linear equations by the linear program engine, and in response to the optimization, generating a description of the manufacturing process.

35. The method of Claim 34 wherein optimizing, based on a predetermined criteria, comprises optimizing based on the internal rate of return of the manufacturing process.

36. The method of Claim 35 wherein providing data representing the linear equations further comprising providing data representing a plurality of linear equations that include price information associated with an input and an output of at least one of the plurality of units as variables.

37. The method of Claim 36 and further comprising automatically accessing a plurality of databases to generate the data representing the plurality of linear equations.

38. The method of Claim 37, wherein providing data further comprising providing data stored in a plurality of spreadsheets.

39. The method of Claim 38, wherein providing data representing a plurality of linear equations further comprises

providing data representing a plurality of linear equations, having, as variables investment cost information associated with at least one of the process units.

40. The method of Claim 39 wherein the plurality of databases comprises at least one database comprising linearized information for at least one variable associated with the plurality of linear equations.

41. A method for designing a manufacturing process having a plurality of units, the method comprising:

providing to a linear program engine data representing a plurality of linear equations describing constraints on the manufacturing process, the linear equations including discrete capital cost information for at least one of the plurality of process units, the discrete capital cost inforamtion including data representing quantified capital costs associated with redundant process units;

optimizing, based on a predetermined criteria, the linear equations by the linear program engine; and

in response to the optimization, generating a description of the manufacturing process.

42. The method of Claim 40, wherein optimizing, based on a predetermined criteria, comprises optimizing based on the internal rate of return of the manufacturing process.

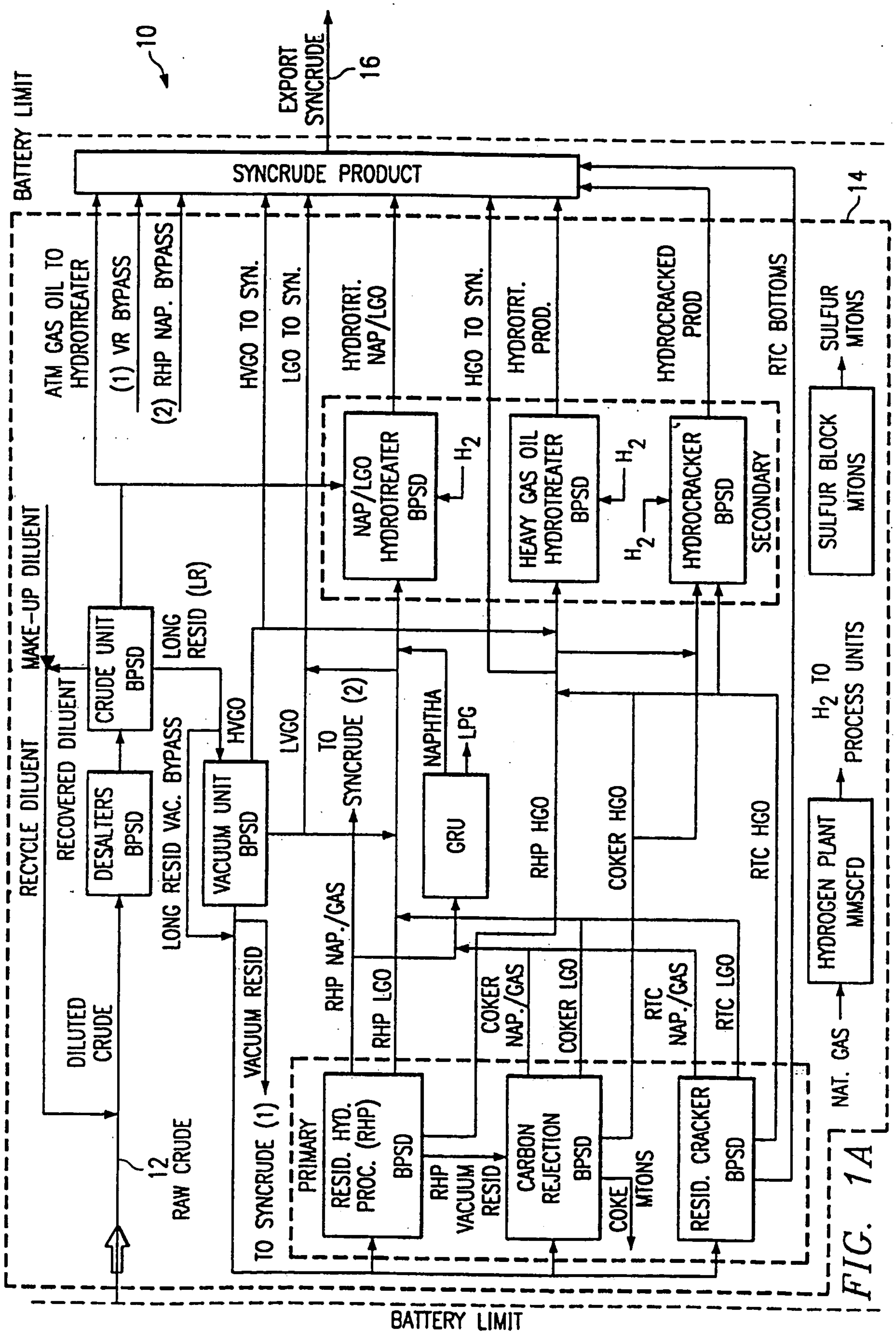
43. The method of Claim 40, wherein providing data representing the linear equations further comprises providing data representing a plurality of linear equations that include energy flow information for at least one of the plurality of units as variables.

44. The method of Claim 40, wherein providing data representing the linear equations further comprises providing data representing a plurality of linear equations that include as variables, price information associated with an input and an output of at least one of the plurality of units.

45. The method of Claim 40, wherein providing data further comprises providing data stored in a plurality of spreadsheets.

46. The method of Claim 40, and further comprising accessing a plurality of databases to generate the data representing the plurality of linear equations.

47. The method of Claim 40, wherein providing data representing a plurality of linear equations further comprises providing data representing a plurality of linear equations having, as variables, investment costs information associated with at least one of the process units.



10
EXPORT SYNCRUDE
16
BATTERY LIMIT
SYNCRUDE PRODUCT
14
ATM GAS OIL TO HYDROTREATER
(1) VR BYPASS
(2) RHP NAP. BYPASS
HVGO TO SYN.
LGO TO SYN.
HYDROTRT. NAP/LGO
HGO TO SYN.
HYDROTRT. PROD.
HYDROCRACKED PROD
RTC BOTTOMS
SULFUR MTONS
NAP/LGO HYDROTREATER BPSD
H2
HEAVY GAS OIL HYDROTREATER BPSD
H2
H2
HYDROCRACKER BPSD
SECONDARY
SULFUR BLOCK MTONS
MAKE-UP DILUENT
RECYCLE DILUENT
RECOVERED DILUENT
CRUDE UNIT BPSD
LONG RESID (LR)
DESALTERS BPSD
LONG RESID VAC. BYPASS
HVGO
VACUUM UNIT BPSD
LVGO
TO SYNCRUDE (2)
NAPHTHA
LPG
GRU
RHP HGO
COKER HGO
RTC HGO
H2 TO PROCESS UNITS
HYDROGEN PLANT MMSCFD
NAT. GAS
DILUTED CRUDE
12
RAW CRUDE
VACUUM RESID
TO SYNCRUDE (1)
RHP NAP./GAS
RHP LGO
COKER NAP./GAS
COKER LGO
RTC NAP./GAS
RTC LGO
PRIMARY
RESID. HYD. PROC. (RHP) BPSD
RHP VACUUM RESID
CARBON REJECTION BPSD
COKE MTONS
RESID. CRACKER BPSD
BATTERY LIMIT

FIG. 1A

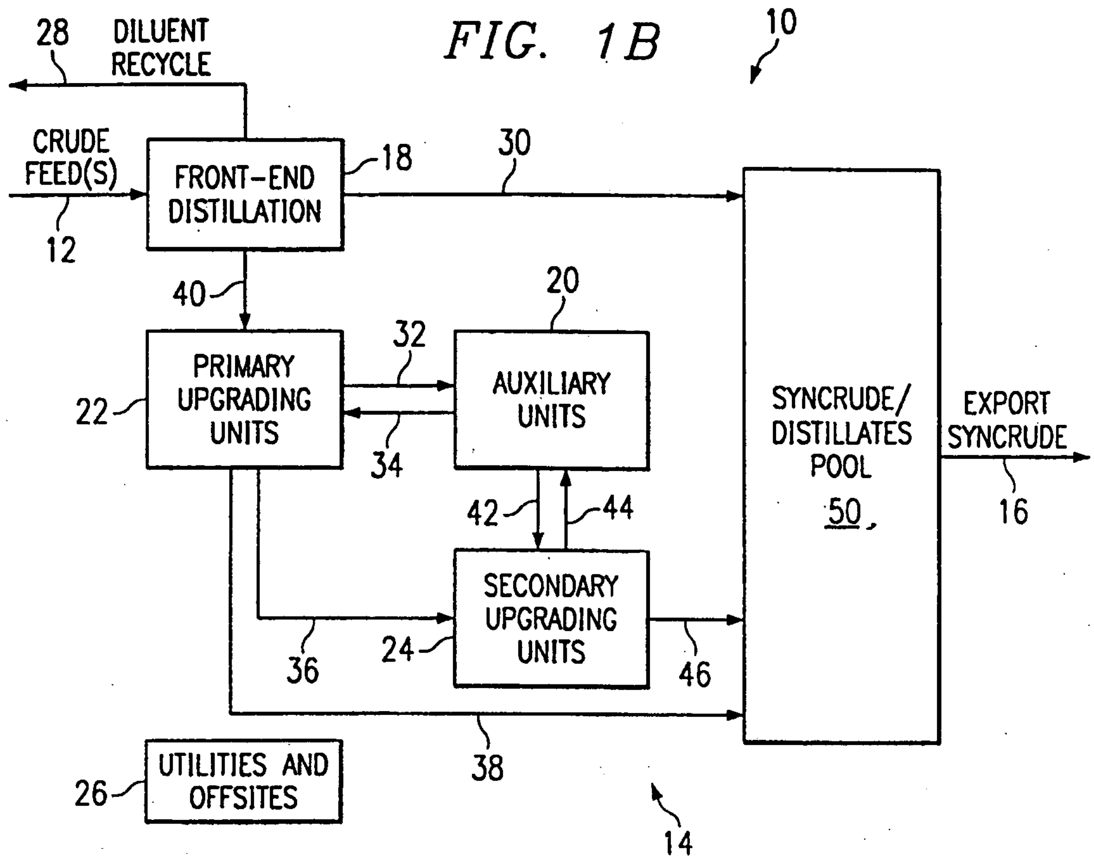


FIG. 1B
10
28
DILUENT RECYCLE
CRUDE FEED(S)
12
FRONT-END DISTILLATION
18
30
40
PRIMARY UPGRADING UNITS
22
32
34
AUXILIARY UNITS
20
42
44
SECONDARY UPGRADING UNITS
24
36
38
46
SYNCRUDE/ DISTILLATES POOL
50
EXPORT SYNCRUDE
16
UTILITIES AND OFFSITES
26
14

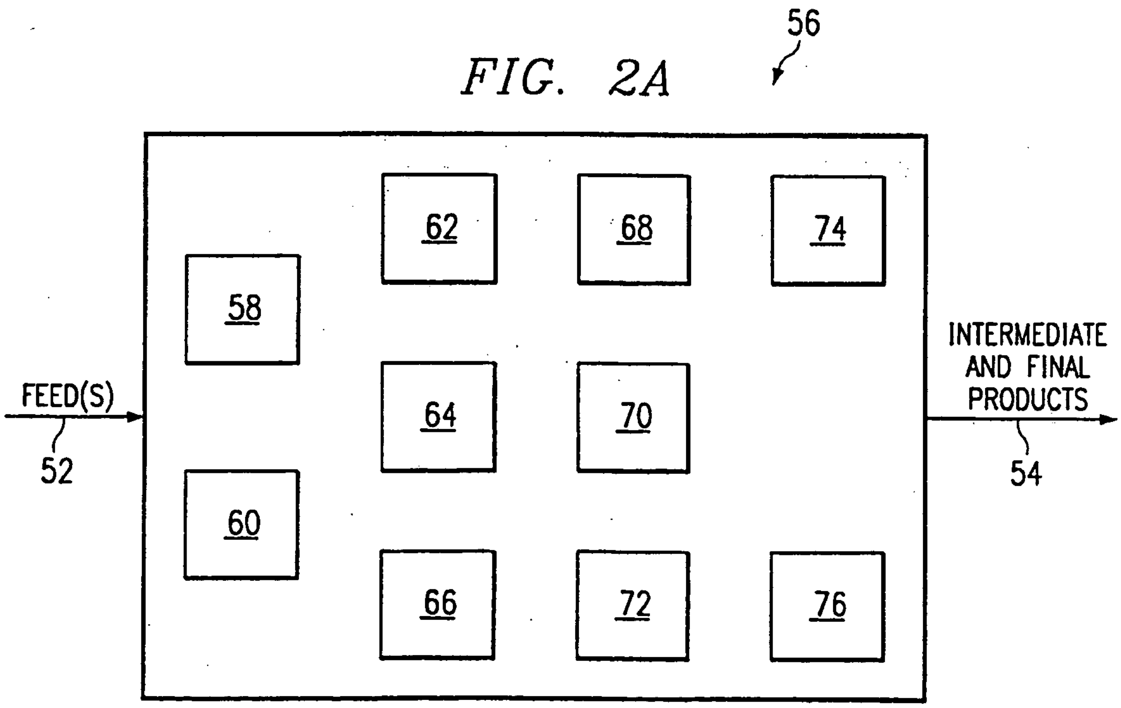


FIG. 2A
56
FEED(S)
52
58
60
62
64
66
68
70
72
74
76
INTERMEDIATE AND FINAL PRODUCTS
54

FIG. 2B

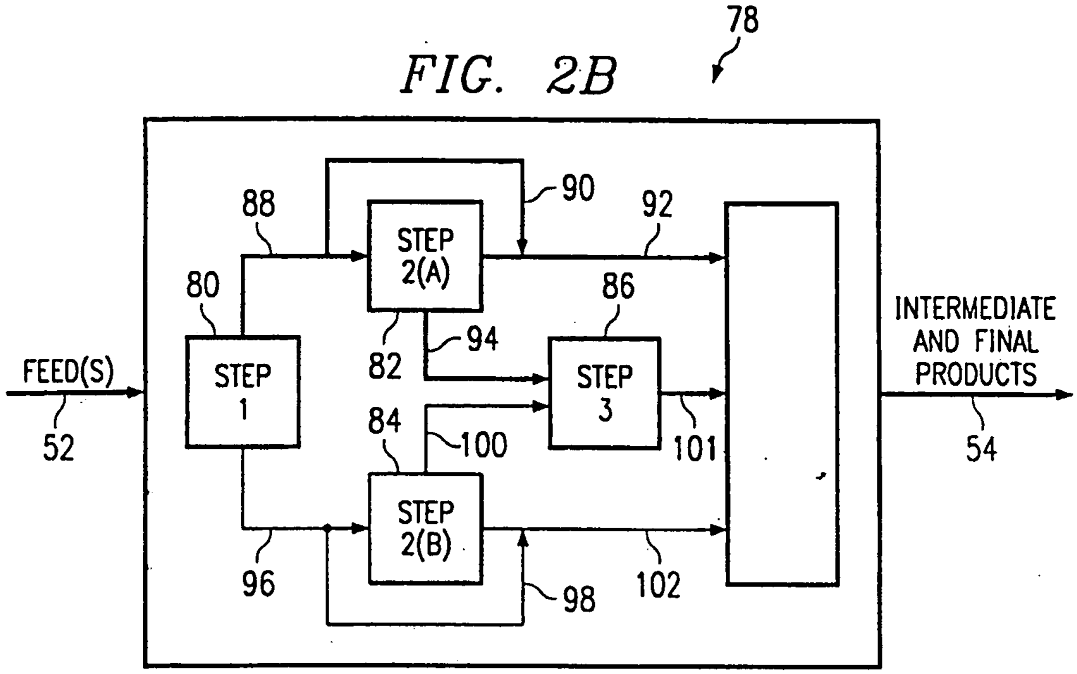
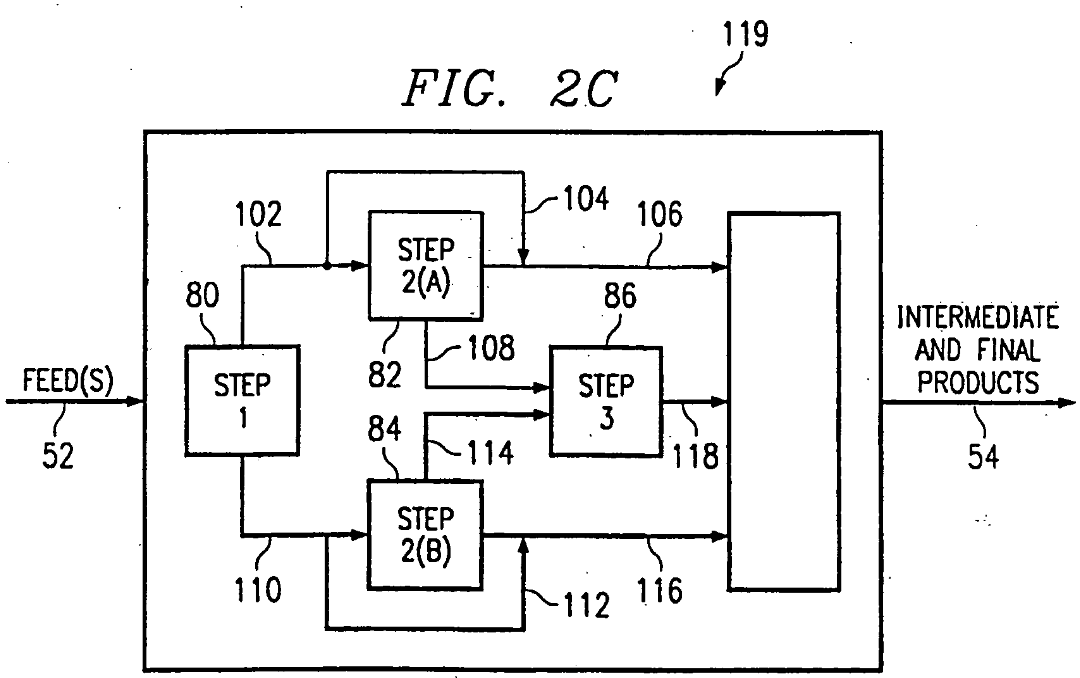

78
STEP 1
STEP 2(A)
STEP 2(B)
STEP 3
FEED(S)
INTERMEDIATE AND FINAL PRODUCTS
52
54
80
82
84
86
88
90
92
94
96
98
100
101
102

FIG. 2C


119
STEP 1
STEP 2(A)
STEP 2(B)
STEP 3
FEED(S)
INTERMEDIATE AND FINAL PRODUCTS
52
54
80
82
84
86
102
104
106
108
110
112
114
116
118

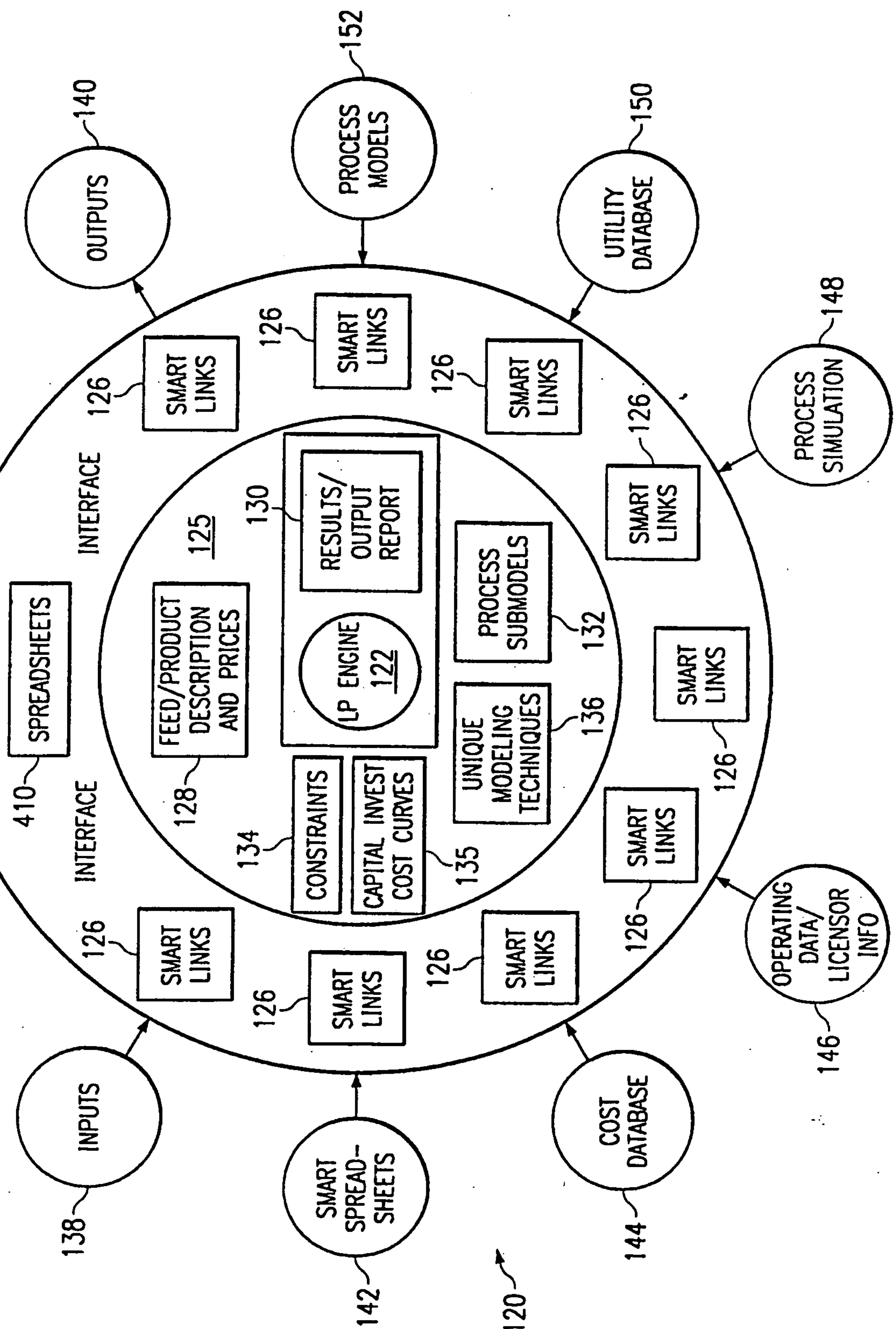

OUTPUTS
140
PROCESS MODELS
152
UTILITY DATABASE
150
PROCESS SIMULATION
148
OPERATING DATA/ LICENSOR INFO
146
COST DATABASE
144
SMART SPREAD- SHEETS
142
INPUTS
138
120
INTERFACE
INTERFACE
124
SPREADSHEETS
410
SMART LINKS
126
125
FEED/PRODUCT DESCRIPTION AND PRICES
128
RESULTS/ OUTPUT REPORT
130
LP ENGINE 122
PROCESS SUBMODELS
132
UNIQUE MODELING TECHNIQUES
136
CONSTRAINTS
134
CAPITAL INVEST COST CURVES
135

FIG. 3

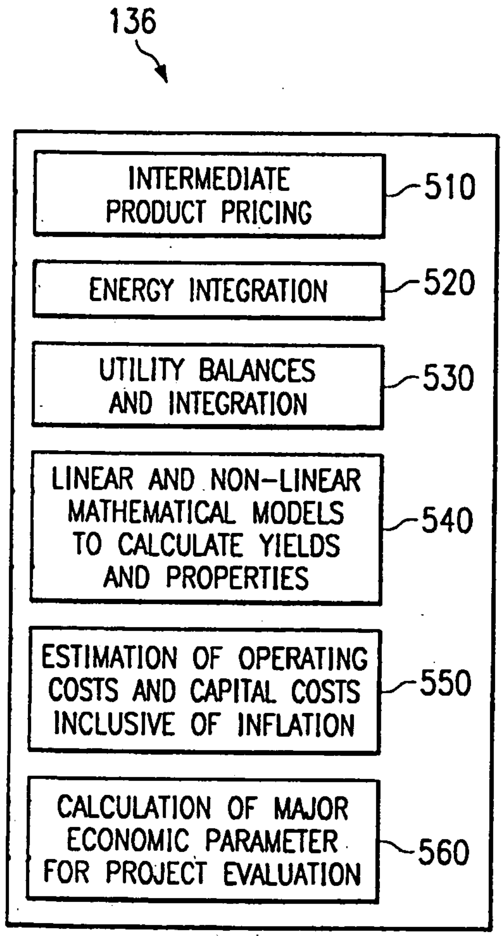

136
INTERMEDIATE PRODUCT PRICING
510
ENERGY INTEGRATION
520
UTILITY BALANCES AND INTEGRATION
530
LINEAR AND NON-LINEAR MATHEMATICAL MODELS TO CALCULATE YIELDS AND PROPERTIES
540
ESTIMATION OF OPERATING COSTS AND CAPITAL COSTS INCLUSIVE OF INFLATION
550
CALCULATION OF MAJOR ECONOMIC PARAMETER FOR PROJECT EVALUATION
560

FIG. 4

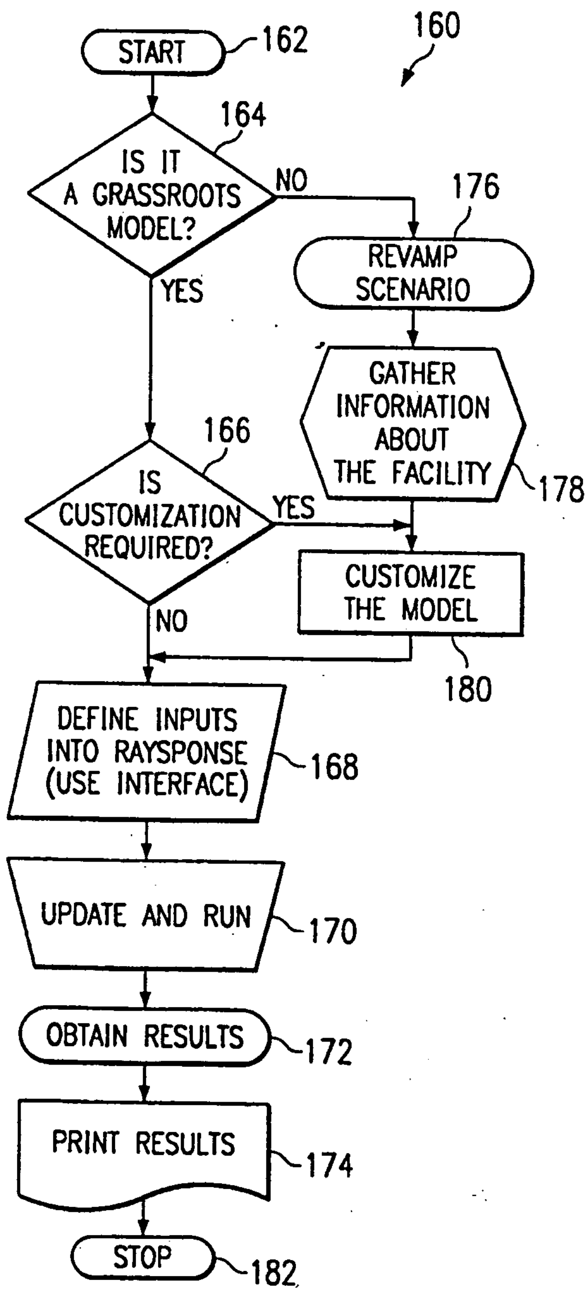

160
START
162
IS IT A GRASSROOTS MODEL?
164
NO
YES
REVAMP SCENARIO
176
GATHER INFORMATION ABOUT THE FACILITY
178
IS CUSTOMIZATION REQUIRED?
166
YES
NO
CUSTOMIZE THE MODEL
180
DEFINE INPUTS INTO RAYSPONSE (USE INTERFACE)
168
UPDATE AND RUN
170
OBTAIN RESULTS
172
PRINT RESULTS
174
STOP
182

FIG. 6

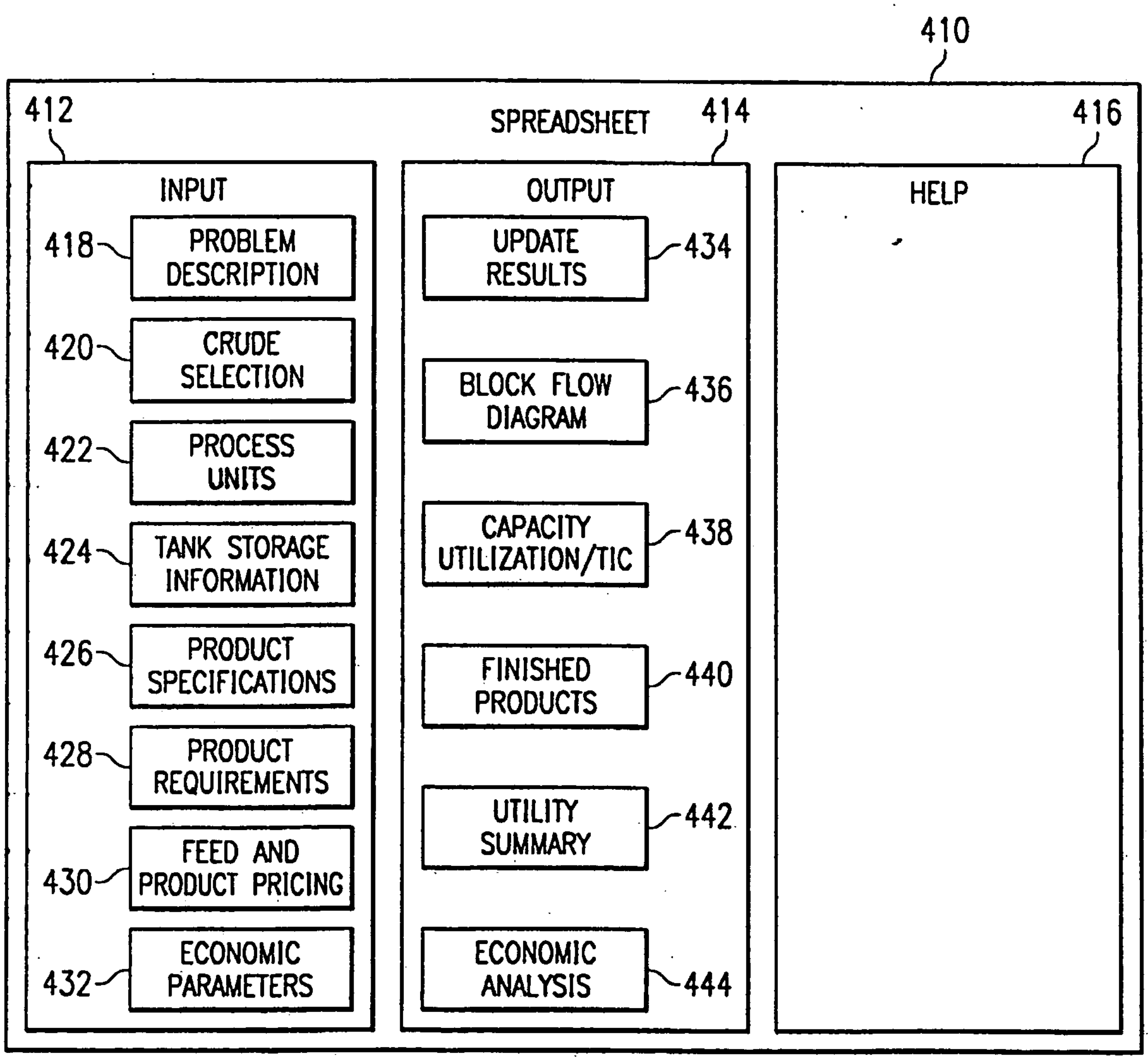

410
412
SPREADSHEET
414
416
INPUT
418
PROBLEM DESCRIPTION
420
CRUDE SELECTION
422
PROCESS UNITS
424
TANK STORAGE INFORMATION
426
PRODUCT SPECIFICATIONS
428
PRODUCT REQUIREMENTS
430
FEED AND PRODUCT PRICING
432
ECONOMIC PARAMETERS
OUTPUT
UPDATE RESULTS
434
BLOCK FLOW DIAGRAM
436
CAPACITY UTILIZATION/TIC
438
FINISHED PRODUCTS
440
UTILITY SUMMARY
442
ECONOMIC ANALYSIS
444
HELP

FIG. 5

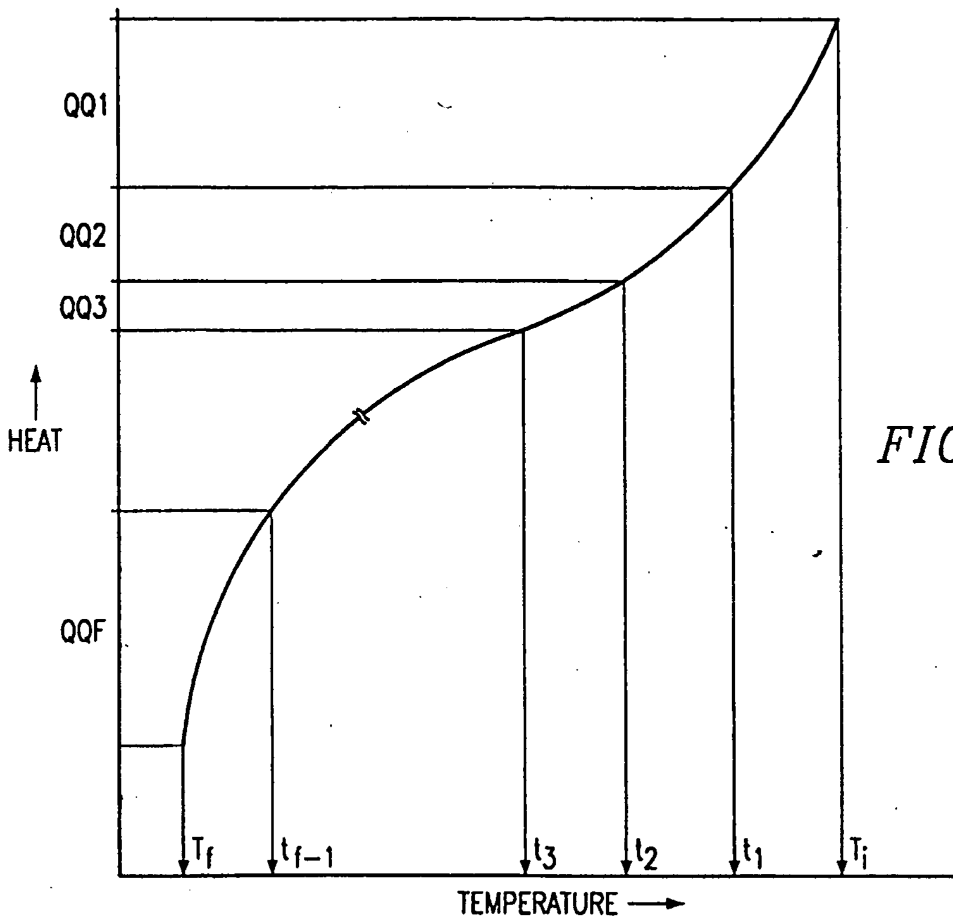

QQ1
QQ2
QQ3
HEAT
QQF
T_f
t_{f-1}
t_3
t_2
t_1
T_i
TEMPERATURE

FIG. 7

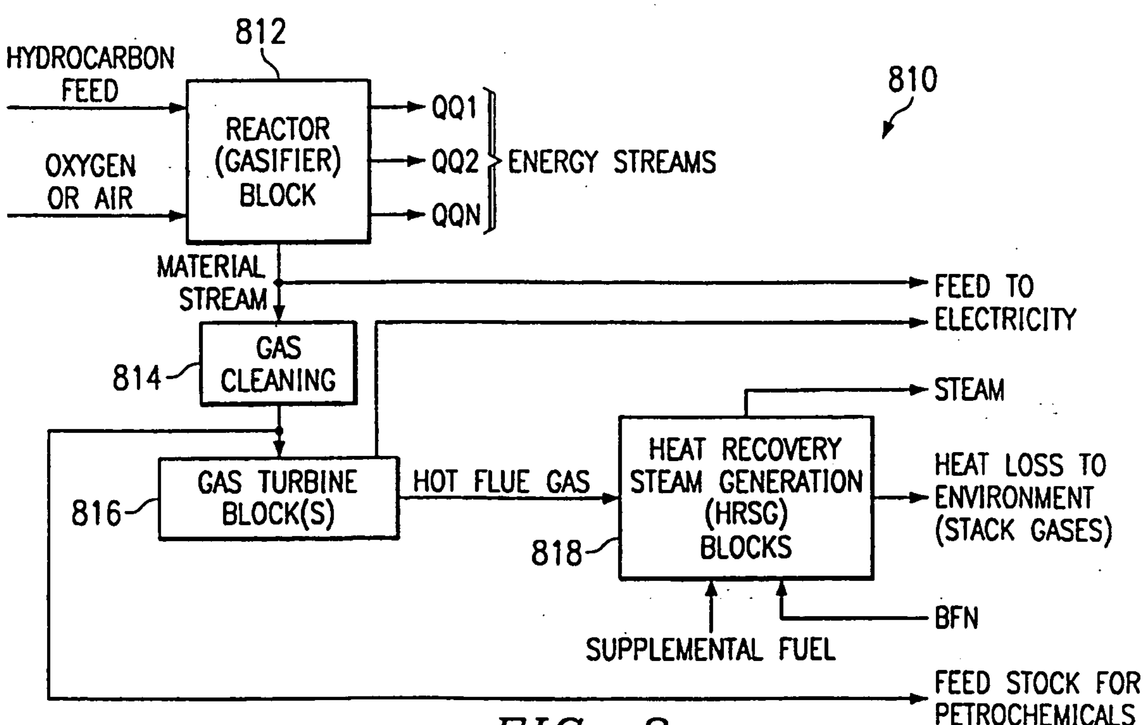

812
HYDROCARBON FEED
OXYGEN OR AIR
REACTOR (GASIFIER) BLOCK
QQ1
QQ2
QQN
ENERGY STREAMS
810
MATERIAL STREAM
FEED TO ELECTRICITY
814
GAS CLEANING
STEAM
816
GAS TURBINE BLOCK(S)
HOT FLUE GAS
HEAT RECOVERY STEAM GENERATION (HRSG) BLOCKS
818
HEAT LOSS TO ENVIRONMENT (STACK GASES)
BFN
SUPPLEMENTAL FUEL
FEED STOCK FOR PETROCHEMICALS

FIG. 8

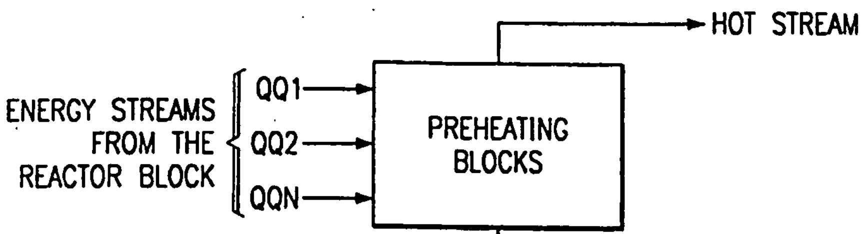


FIG. 9A

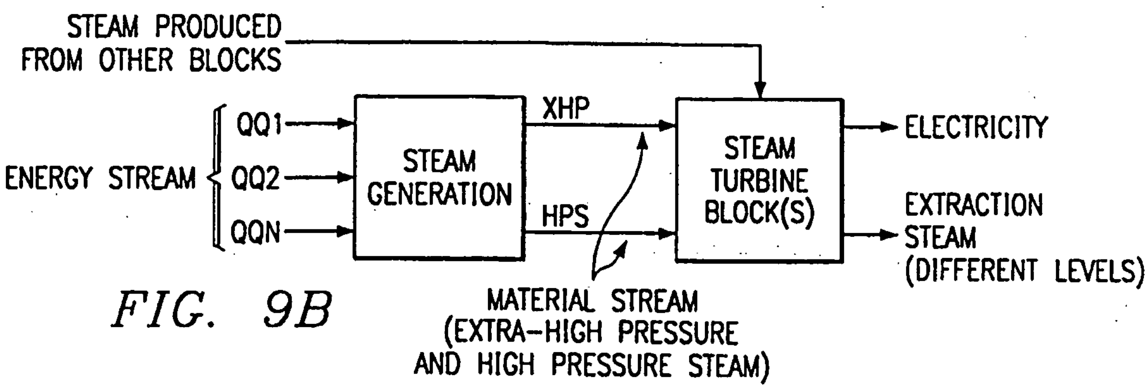


FIG. 9B

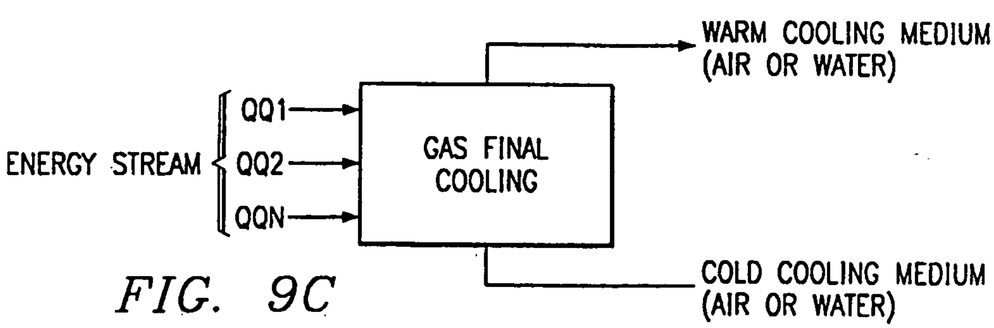


FIG. 9C

FIG. 10A

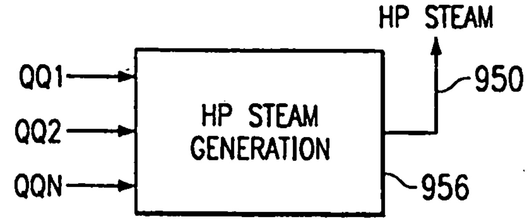


FIG. 10B

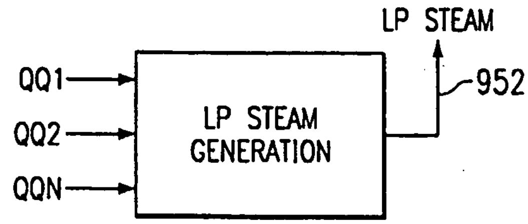
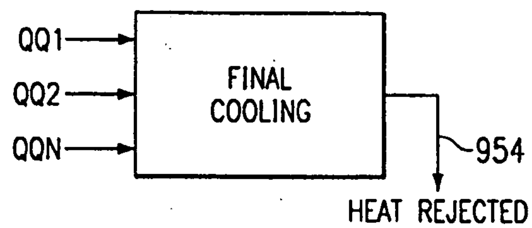
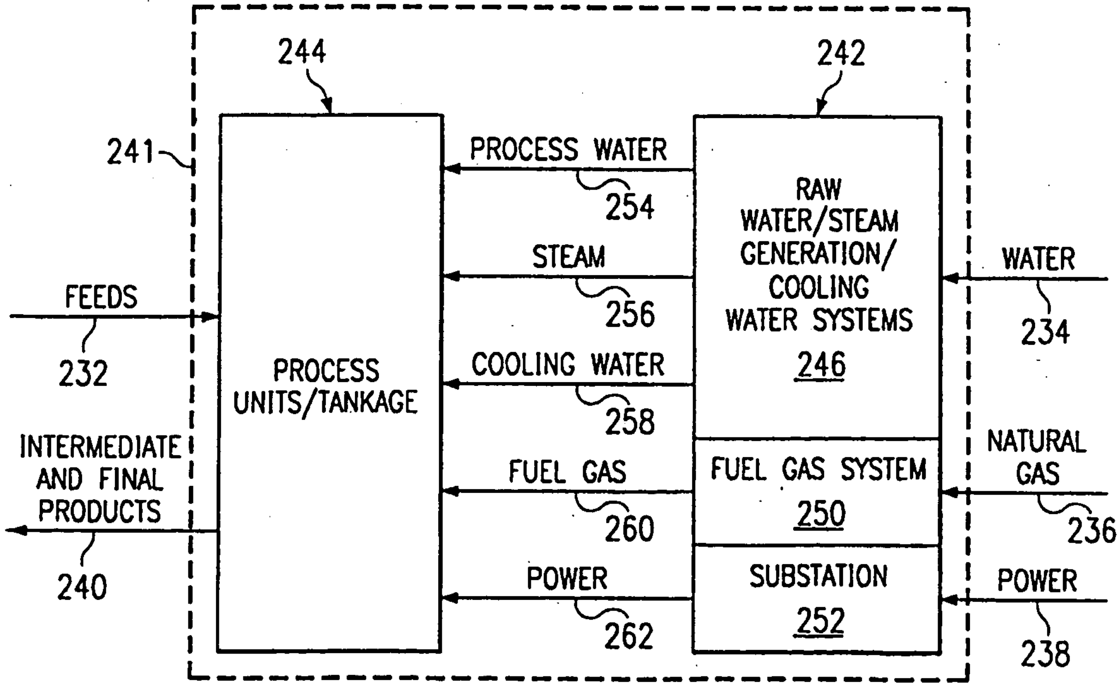


FIG. 10C



230

FIG. 11



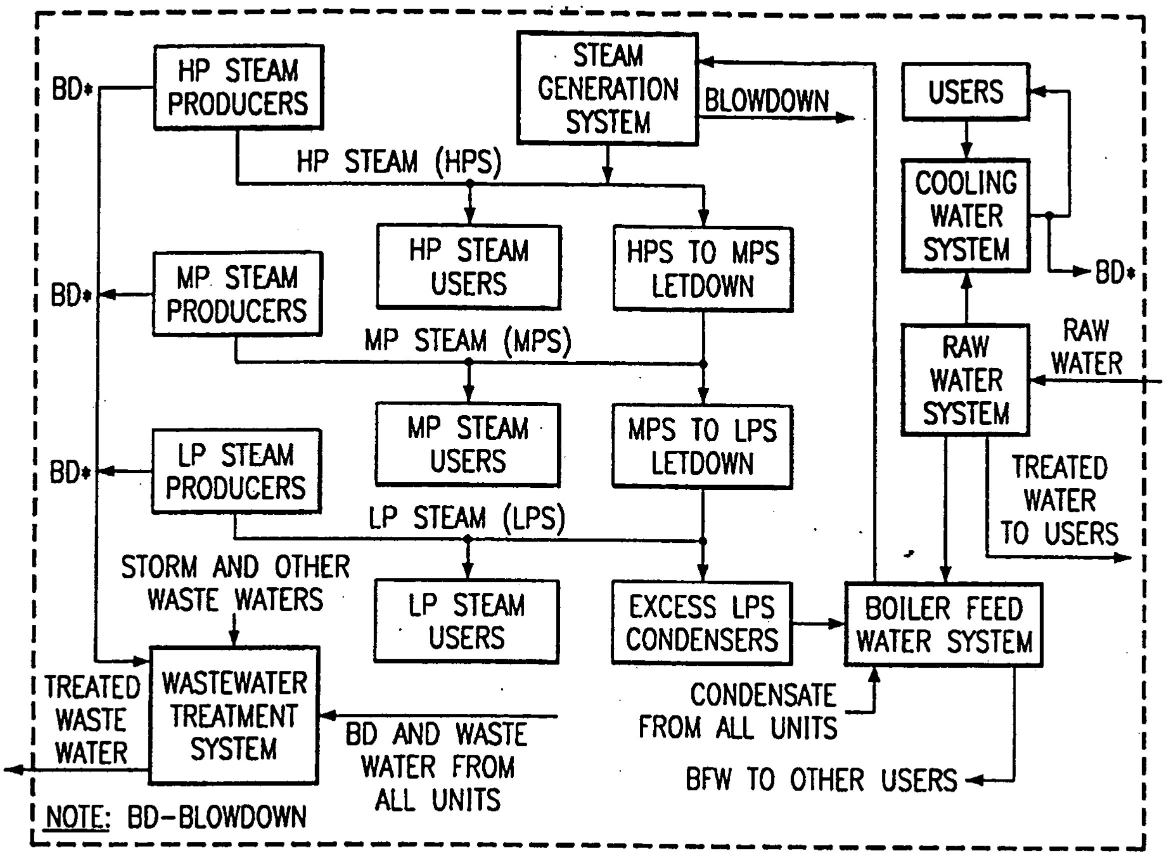

HP STEAM PRODUCERS
STEAM GENERATION SYSTEM
BLOWDOWN
USERS
BD*
HP STEAM (HPS)
HP STEAM USERS
HPS TO MPS LETDOWN
COOLING WATER SYSTEM
BD*
MP STEAM PRODUCERS
BD*
MP STEAM (MPS)
RAW WATER SYSTEM
RAW WATER
MP STEAM USERS
MPS TO LPS LETDOWN
BD*
LP STEAM PRODUCERS
LP STEAM (LPS)
TREATED WATER TO USERS
STORM AND OTHER WASTE WATERS
LP STEAM USERS
EXCESS LPS CONDENSERS
BOILER FEED WATER SYSTEM
TREATED WASTE WATER
WASTEWATER TREATMENT SYSTEM
BD AND WASTE WATER FROM ALL UNITS
CONDENSATE FROM ALL UNITS
BFW TO OTHER USERS
NOTE: BD-BLOWDOWN

FIG. 12

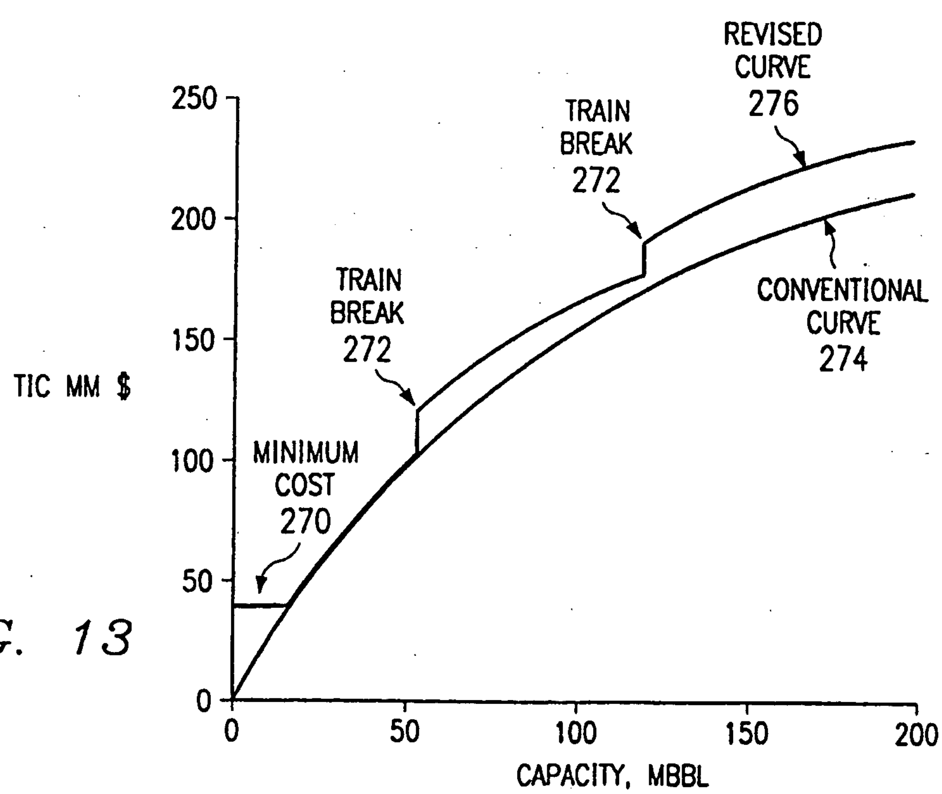
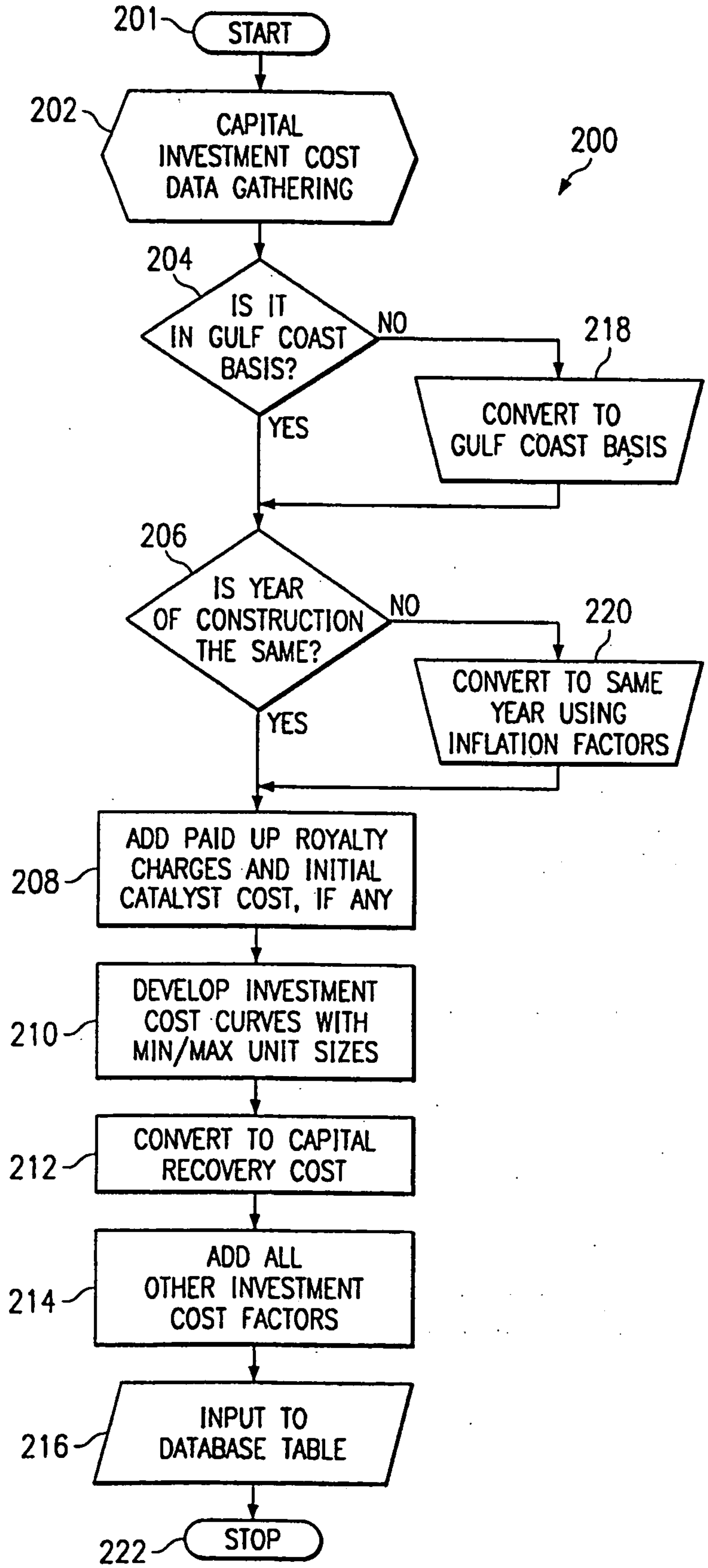
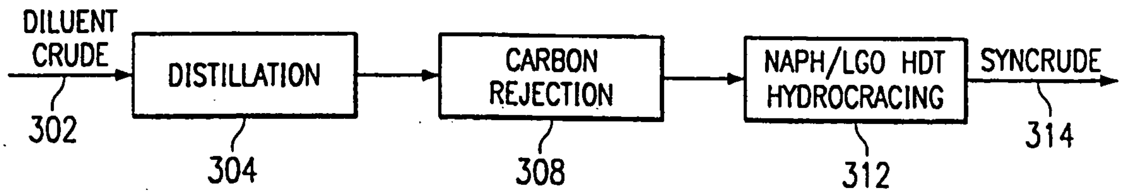

REVISED CURVE 276
TRAIN BREAK 272
TRAIN BREAK 272
CONVENTIONAL CURVE 274
MINIMUM COST 270
TIC MM $
250
200
150
100
50
0
0
50
100
150
200
CAPACITY, MBBL

FIG. 13

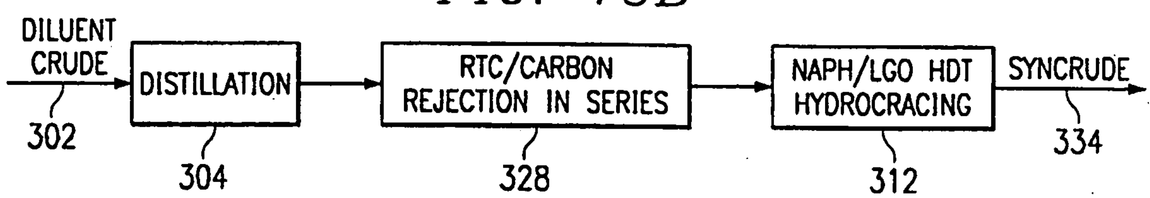
FIG. 14


201
START
202
CAPITAL INVESTMENT COST DATA GATHERING
200
204
IS IT IN GULF COAST BASIS?
NO
YES
218
CONVERT TO GULF COAST BASIS
206
IS YEAR OF CONSTRUCTION THE SAME?
NO
YES
220
CONVERT TO SAME YEAR USING INFLATION FACTORS
208
ADD PAID UP ROYALTY CHARGES AND INITIAL CATALYST COST, IF ANY
210
DEVELOP INVESTMENT COST CURVES WITH MIN/MAX UNIT SIZES
212
CONVERT TO CAPITAL RECOVERY COST
214
ADD ALL OTHER INVESTMENT COST FACTORS
216
INPUT TO DATABASE TABLE
222
STOP

300
FIG. 15A



320
FIG. 15B



340
FIG. 15C